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CHILD DEVELOPMENT

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MEASURES WHICH CHARACTERIZE THE INDIVIDUAL DURING THE DEVELOPMENT OF BEHAVIOR IN EARLY LIFE[1]

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I. INTRODUCTION

The studies on the development of behavior which have been reported from the Normal Child Development Study were undertaken with a specific objective, namely, to discover in the unfolding pattern of development evidence of maturation in the central nervous system. This primary purpose has of necessity molded the plan of observation and the scoring of results. The cues to interpretation have been furnished by anatomical studies of the brain by Tilney (1), by Conel (2), and occasionally by others. Individual idiosyncrasies in the form of behavior have been regarded as of minor importance; a fundamental sequence of developmental features independent of the idiosyncrasies has been looked for. In particular, the studies have not aimed at the establishment of normal standards of achievement. Rather, emphasis has been placed on the sequence of events which lead to the acquisition of mature behavior. Aside from the primary purpose, however, it is clear that the records should contain data capable of characterizing the individual child, that is, of locating the position of the individual against the background furnished by his peers. Since the serial observations of different behavior activities were concerned for the most part with the same group of infants, it follows that the achievement of the individual can be rated from several independently assembled sets of data. The purpose of the present communication is to examine a few of the possibilities for rating the individual on the basis of longitudinal observations of behavior and to assess the significance of dispersion among several independent ratings.

Fundamentally development is a dynamic phenomenon characterized by continuous change. The laws which guide its course are not given by measurements at an early age repeated at an older age. Rather they are concerned with the nature of the transition which leads one set of measurements to give way to another. Satisfactory elucidation of the laws of change demands frequent longitudinal observation and, if the path of development is to be charted, the quantities of measurement must be expressed in mensurable units. Several previous papers (3) from the Normal Child Development Study dealing with developmental phenomena have illustrated the way in which the velocity constant yielded by an exponential equation can be utilized to characterize the motion of growth. In the studies of the development of behavior with which we are now concerned, frequent longitudinal observations were recorded. However, the observations have not dealt with features which can be measured in mensurable units and a full description of the element of change cannot be given as a constant in a mathematical equation. It is clear, however, that achievement or level of attainment at any age can be broken down into at least two parts, one, the level at birth or at the age arbitrarily

[1] *From the Normal Child Development Study of the Department of Pediatrics, Columbia University and the Babies Hospital.*

selected for beginning observations and, two, the subsequent velocity of change up to the designated age. Even though an achievement in behavior, such as the ability to stand without support, cannot be measured in units, nevertheless, it can be used to establish a rank order in development among a group of children. Here, the order is determined by the earliest age at which the ability is acquired and the two components of development, level at birth and velocity of change, are expressed for each child in terms which give his relative standing in the group.

Details of the procedure for manipulating longitudinal observations of behavior so as to obtain the measures of relative development will be given in an ensuing section. At the moment attention must be given to the usefulness of formulating such measures. Here, it would seem, that the objective of providing a "rating" for the child was of secondary importance to an understanding of the interrelationships among concurrently acquired but different forms of behavior. An example will be helpful in clarifying this point.

The developmental processes which lead to coordinated ability in erect locomotion may be said to begin with the reflex stepping movements which characterize the newborn infant. Likewise the processes which lead to perfection in the movements of creeping may be regarded as starting with the reflex kicking exhibited by the newborn infant in a prone position. Through many months of infancy both types of behavior are concurrently showing developmental change. It is of more than passing interest to inquire the extent to which rapid development in one behavior is associated with similarly rapid development in the other. With the illustration given each of the two forms of behavior is predominantly neuromotor and, in part, the velocity of development in each will depend on identical or closely associated maturative change in the motor cortex and in the connecting neuromotor pathways. Later when the frontal lobes begin to function and the movements assume the characteristics of voluntary purposeful action, both behaviors may again be modified by identical or closely associated developmental changes. Now, it is clear that if the velocity of development in the two activities depended solely on identical central changes, it would proceed at the same rate in both behaviors. That is, the correlation coefficient between measures of the two velocities would deviate from unity only by an amount dependent on errors of observation in determining the measures. It is undoubtedly true that such errors can be large, particularly when observations are not recorded daily. But also it is unreasonable to think that development in the two activities can depend solely on identical central changes. The muscle groups responsible for the two behaviors and their cortical representations are not identical although they undoubtedly overlap. Moreover, there are other easily observable phenomena in the development of behavior which must prevent complete parallelism between two activities. When the age of awareness has been reached the beginning of a new skill may completely absorb the attention and interest of the child. For the time being the rate of development in this specific field can be extraordinarily fast; at the same time development in other fields can be halted or even undergo regression. With other types of behavior, such as reaching for a lure which the child has seen, the participation of sensory nerves

and sensory areas in the brain is apparent. These additional factors can be expected to modify the developmental rate and prevent complete parallelism with forms of behavior which do not involve such factors.

Although from the standpoint of understanding the dependence and independence of development in different behaviors, there is a real advantage in isolating the components which together lead to degree of achievement at any age, it does not necessarily follow that one or the other of the components will form a better gauge for assessing individual development than achievement itself. In a later portion of this paper it will be shown that better correlations are obtained between measures of ultimate achievement in different behaviors than between measures which express solely the rate of change in each behavior. This seeming paradox may be determined in part by positive associations between rate of change and developmental status at birth so that both are of equal importance in determining achievement and so that errors involved in isolating the components are eliminated.

II. THE NATURE OF THE PLUS-MINUS DATA

The analysis to be described has been applied to five behavior activities, which will be identified by the terms "creeping", "sitting", "walking", "reaction to pin-prick", and "reaching for a lure". An activity may be defined as the entire developmental course of a selected function, such as creeping or walking. For purposes of study, each activity was resolved into a number of <u>phases</u>, or stages of development. The phases were defined in such a way as to aid the identification of gross behavior changes with the maturation of the central nervous system.

For example, in the activity of walking, seven phases had been selected as reflecting significant stages of development. The newborn phase (A) consists in reflex stepping when the infant is held in an erect position. In the second phase (B), the inhibitory or static phase, the infant shows more equilibratory control of the head with respect to the shoulder girdle, and less of the early reflex stepping. The succeeding phases demarcate further progress in walking until in the mature phase (G), the child walks independently, coordinates the swinging of his arms with his leg movements, and shows heel-toe progression in his steps. Complete descriptions of the sequential developmental phases involved in the activity of walking, as well as of the phases in the other four activities, have already been published by McGraw (4).

Data on each of the activities studied were recorded as follows: serial observations were made on some 60 children, with a few of them being observed daily, and the remainder either about once a week, or once every two weeks. At each observation, the child was rated by assigning a plus value to the phase or phases which most accurately represented his behavior, and minus values to the remaining phases.

Thus in walking a typical child would be in phase A alone until an age of about 100 days. Then, for some 40 days he might be sometimes in A, sometimes in B, and sometimes in both. Thereafter for a short period B alone would be manifested, but soon C would make its appearance,

and so on.

The data representing the presence or absence of each phase in a certain activity consist, therefore, in a set of plus and minus ratings, one for each time that the child was observed.

III. CALCULATION OF THE PHASE AGES

In general, the plus ratings - denoting the presence of a phase - tend roughly to cluster about some average age. Usually there is a short period of time during which the phase has a plus recorded at every observation, preceded by an interval during which the phase is gradually asserting dominance over the preceding one, and followed by a period in which it gradually passes out.

Thus the average age at which each phase was manifested for a given child is roughly the age at which it achieved its greatest dominance, and was, therefore, his characteristic mode of behavior. Such a mean age is probably the best single number to represent the data. It also has other advantages. Since its calculation uses all the data on the phase, it can be obtained even when the observations are very sparse, so sparse that only one or two pluses are recorded.

Briefly then, for each phase an average age, or phase age, can be calculated. This is a number characterizing the entire phase and giving approximately its time of greatest dominance. The details of the calculation are described in Appendix A.

By averaging the phase ages for all of the children, a mean phase age most representative of the behavior of the entire group (group phase age) can be calculated. Then, any child's developmental status may be compared with that of the group as a whole. For example, if Oscar's phase age for phase B in walking is 200 days, and the group phase age is only 163 days, then Oscar is 37 days behind the group in his age of attaining the particular stage of development concerned. Since for each child a comparison of this sort may be made for each phase of all the activities studied, one can obtain a large number of measures of that child's attainment relative to the average performance of the group. One way of describing a child's relative motor performance would be simply to tabulate how many days he is ahead of the group or behind it for all the phases. This method would, however, yield too many numbers for easy appraisal of the results. Also there would be no direct measure of the dynamic component of achievement, namely, of its velocity, or rate of progression. This most important aspect of development, as distinguished from mere static continuation, would be entirely neglected.

A method was therefore devised which, in yielding two constants descriptive within certain limits of a child's entire performance in an activity, not only condensed the numerical data but also gave prominence to the dynamic character of growth.

IV. METHOD OF OBTAINING BEHAVIOR CONSTANTS

Table 1 summarizes the data with respect to each activity studied and for each of the phases used in the analysis. A total of 40 children

TABLE 1

SUMMARY OF GROUP DATA ON THE FIVE BEHAVIOR ACTIVITIES
EMBODIED IN THE PRESENT ANALYSIS

n is the number of children used for each phase;
θ, the group phase age in days.

Activity	Phase	n	θ	Activity	Phase	n	θ
Creeping	A	40	49	Walking	A	40	65
	B	40	105		B	40	163
	C	40	166		C	40	247
	D	37	206		D	40	335
	E	30	216		E	34	462
	F	36	252				
	G	35	275	Reaction to pin-prick	1A	40	60
					1B	40	171
Sitting	1A	40	51		1C	36	297
	1B	40	110		2A	39	79
	1C	40	198		2B	37	239
	2A	40	40				
	2B	40	92	Reaching for a lure	A	28	44
	2C	38	137		B	28	113
	2D	38	181		C	27	218
	2E	37	217		D	28	392

were available for determining most of the group phase ages. In several instances, however, the data were so sparse on some of the phases included in the original study that they were omitted from the analysis; in other instances, the number of children who could be used was less than 40. Particularly with the last two activities, reaction to pin-prick and reaching for a lure, there was a relative paucity of data. To avoid undue error from this source, the data from the two activities were combined in the analysis which follows; that is, both activities were treated as if they represented a single expression of behavior. Justification for the procedure can be found in the circumstance that both activities depend to some extent on sensory perception whereas the other three activities are more nearly purely motor.

It was found empirically that if, for any activity, a child's phase ages are plotted against the corresponding group phase ages, then the points obtained scatter fairly closely about a straight line. Such

plots for 3 children and the several activities are shown in Fig. 1. Since the points for each activity lie approximately on a straight line, a linear equation can be fitted to the data. This equation, which relates the individual phase ages to those of the group, can be written in the form:

$$t_c = a\theta + c$$

where t_c is now simply the chronological age of the individual, and θ, the chronological age of the "group" (i.e., of the norm). a and c are constants, different in general, for different children and for different activities.

The constant a is the slope of the line, or the rate of change of t_c with θ. It is the ratio of the average rate of development in the group to the rate of development for the individual. (See Appendix C.) Expressed in percentage, it gives the number of days which the individual takes to make the developmental progress which the "group" makes in 100 days. An individual with an a of less than 100 per cent requires less time than does the "group", and hence is faster than the average child; one with an a greater than 100 per cent requires more time, and hence is slower.

The constant c gives the value of t_c when θ is zero. It indicates when the individual reached the stage of development which the average child has at birth. For example, if c is +20 days for some child, then that child achieved at 20 days what the group had achieved at birth. Hence he is 20 days behind the group. In general, a positive c means that the child is behind the group, and a negative c that he is ahead.

Within the error of fit of the line to the points and the original error of determining the mid-points of the phases, the two constants a and c describe completely the child's behavior in the given activity, relative to that of the group. The age equivalence constant, a, gives his relative rate of development, and the constant c, his relative status at birth. However, attention should be called to the limited significance of the statement that relative development in any one of the activities can be represented by a linear function. The method of choosing group averages as the independent variable in each equation makes it obligatory only that the sum or the average of the lines for all individuals will be linear because the points on the average line are in fact the group averages. A priori, however, it is conceivable that the development of some individuals could be represented better by lines with a slight concavity and others by lines with a compensatory degree of convexity. Within the limits imposed by errors of observation it has not been possible to discern deviations from linearity in the developmental lines. This fact means that a more complicated formulation of developmental progress is not justified by the data. Nevertheless, it is important to remember that the use of the straight line may limit the descriptive value of its constants if, in truth, the functions should be slightly curvilinear.

The method of fitting the lines to the data is described in Appendix B.

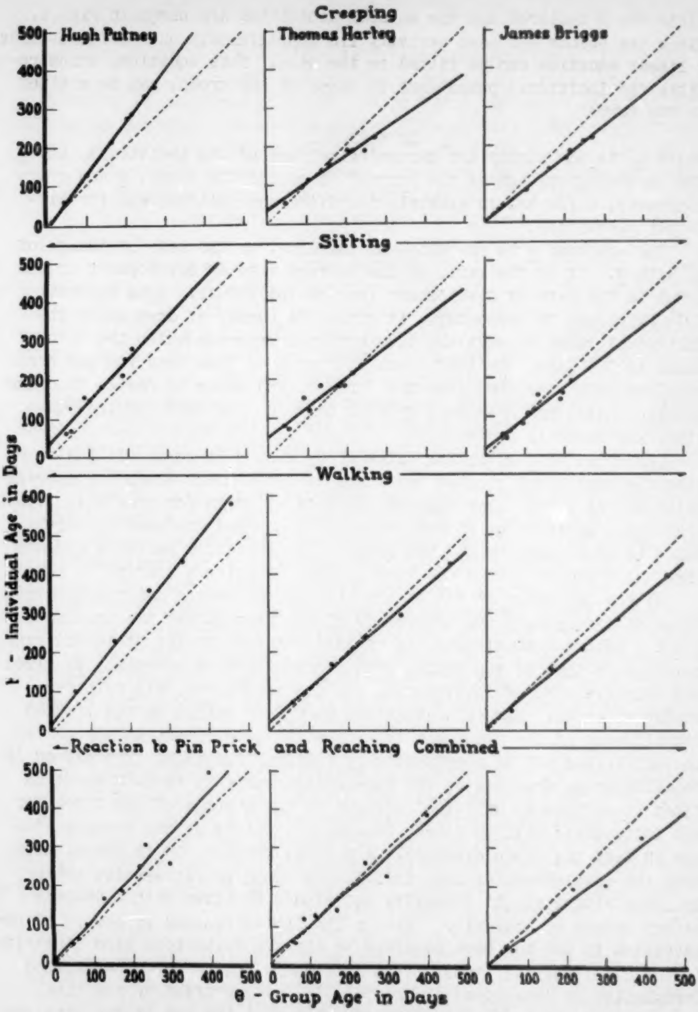

Fig. 1. Illustrative graphs for 3 children showing the relation between the individual and the group in the development of creeping, sitting, walking and of reaction to pin-prick and reaching for a lure combined. The path of individual development is traced by the heavy line; the deviation of the heavy line from the dotted line, drawn at 45 degrees through the origin, indicates the relation of individual development to group development.

V. COMPARISON OF CHILDREN AND ACTIVITIES

Now that a mathematical description of a child's behavior in an activity has been obtained, one can compare directly different children and also different activities. It is of considerable interest to determine how much alike a child's behavior in one activity is to that in another. If children are to retain their individuality, one must expect to find that the variation among the different activities for 1 child is smaller than the variation among different children. More precisely, for any measure of development (for example, the slope a above), one would expect that F, the ratio of the variance among children to the variance within children, would be greater than one. The significance of F in terms of conventional probability can be determined from tables in standard reference books on statistics (5). This significance depends not only on the actual value of the ratio of the variances but also on the number of observations from which it has been computed. When F can be shown to be significant, the fact will constitute proof that the measure of development does to some extent at least characterize the individual child and that to the same extent it can serve to define his position against the background of his peers.

The first calculations were made using the slopes (age equivalence constants) a for 40 children, and the three activities, creeping, sitting, and walking. In this case F was 2.714, with a probability of less than 0.1 per cent[2] of occurrence by random chance in a population with a true F of unity. Since the square root of the variance is proportional to the average deviation,[3] and the square root of F is 1.648, the average deviation between the means of the a values for different children is about $\frac{5}{3}$ of that within children. Hence it is apparent that while the children are characterized significantly by the average values of a for creeping, sitting, and walking, they are not characterized very sharply; the spread within a child is almost as great as that between children.

Figure 2A is given to illustrate the various factors involved in the calculation of F. The ordinate of this plot is the slope constant a. The 40 children are equally spaced along the abscissa, and arranged in order of increasing average a. At each child's abscissa are plotted his slopes for creeping, sitting, and walking, and the average of these. The scatter of the individual points about a line through their averages is the scatter within children. The scatter of the averages about their mean (100%) is the scatter among children.

The question of how well one can predict a child's behavior in one activity from a knowledge of his behavior in another, can be answered by calculating the correlation coefficients between the various pairs of activities. For the constants a, these coefficients with their standard errors are: between creeping and sitting, $+0.364 \pm 0.138$; between sitting and walking, $+0.436 \pm 0.129$; and between walking and creeping, $+0.318 \pm 0.144$. Since by means of a correlation in which r

[2] *It is customary among current statistical workers to accept the 5 per cent level as indicative of a significant difference between the groups being compared; the 1 per cent level is accepted as evidence of a highly significant difference.*

[3] *Average arithmetic deviation—i.e., without regard to sign.*

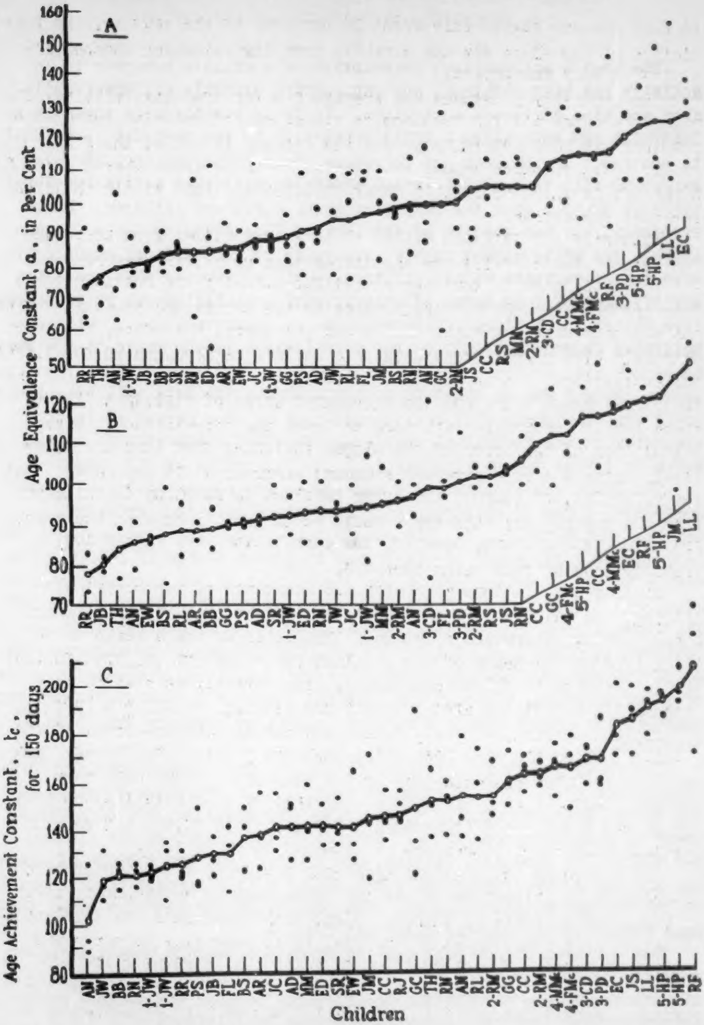

Fig. 2. Pictorial representation of the relation between variability in behavior performance throughout a group of children and variability within each child throughout several activities. The construction of the graph is explained in the text. Graph A depicts the age equivalence constant, a, in creeping, sitting and walking. Graph B shows the average a for creeping, sitting and walking in relation to the a for reaction to pin-prick and reaching for a lure combined. Graph C represents the value of t_c for a at 150 days for creeping, sitting and walking.

is 0.45 one can remove only about 10 per cent of the scatter, the prediction of the slope for one activity from its value for another activity is very inaccurate.

The association between the average $\underline{a}$'s for creeping, sitting, and walking and the $\underline{a}$'s for reaction to pin-prick and reaching for a lure combined was also determined. In this case, F is 2.774, and $\underline{r}$ is +0.417 $\pm$ 0.126, which values are similar to those given above. Fig. 2B shows graphically the scatter among children and that within children for this comparison.

Evidently the variance within children can differ from zero, and the correlation coefficients can differ from unity, for two reasons. The first of these is that the activities actually are not identical. They involve somewhat different areas in the cortex and somewhat different neuromuscular pathways. It is not necessary, therefore, to expect extremely high correlations between a child's performance in two different activities. But in addition there is the error of determining the individual phase ages, and the subsequent error of fitting a line to these data. Error also will tend to lower the correlations. Direct calculation of the error of the slopes indicates that they are relatively quite accurate (average standard error about 15 per cent). But there remains, of course, the error involved in sampling 40 children from the population; this error could be larger. Even when the errors are taken into account, however, the correlations are rather low, probably none of them being over 0.6.

Similar calculations made with the constants $\underline{c}$, for creeping, sitting, and walking gave an F of 1.744, with a probability of about 2 per cent of occurrence by chance. The ratio of the average deviation between the means of the $\underline{c}$ values for different children to that within children is $\sqrt{1.744}$ or about $\frac{4}{3}$. The correlation coefficients between the activities are: creeping and sitting, -0.071 $\pm$ 0.160; sitting and walking, +0.242 $\pm$ 0.150; and walking and creeping, +0.489 $\pm$ 0.122. These are much less alike than the $\underline{r}$'s for the slopes. The children are thus characterized by the constants $\underline{c}$, but only very poorly. Inasmuch as $\underline{c}$ is a number obtained by extrapolating the line beyond the first point (this occurs for a $\underline{\theta}$ of 44 days), not so much developmental significance can be attached to it as to $\underline{a}$.

The foregoing computations have been concerned with quantitative measures of individualism in the two components of development, level at birth and velocity of change. Since both components are involved in determining achievement at any age, it is essential to carry the analysis further. The calculation of F for the constant $\underline{c}$ involved the determination of the average variance within each child, and the variance among different children for the age at zero development, or the value of $\underline{t_c}$ when $\underline{\theta}$ is zero. Similar computations can be made for the values of $\underline{t_c}$ for a $\underline{\theta}$ of 100 days, of 200 days, etc. Each $\underline{t_c}$ represents the age at which the child in question achieved a certain stage of development - i.e., that represented by $\underline{\theta}$ = 100 days, or a $\underline{\theta}$ of 200 days, as the case may be. The set of numbers $\underline{t_c}$ for a $\underline{\theta}$ of 100 days can be determined from the equation

$$\underline{t_c} = 100\,\underline{a} + \underline{c}$$

and consists of a different $\underline{t_c}$ for each child and for each activity.

The constants $\underline{a}$ and $\underline{c}$ obtained for 40 children in the activities creeping, sitting, and walking were used. The variance within children and that among children were calculated for a sufficient number of values of $\underline{\theta}$ to obtain curves of these quantities against $\underline{\theta}$. These curves are shown in Figure 3. Since the range of $\underline{\theta}$ for which there are data (i.e., group phase ages) for all three activities is only from about 50 days to 220 days, the extrapolation of the curves beyond this range can have little meaning.

It is to be noted that the curves for the variances are segments of parabolas. This is a necessary consequence of fitting straight lines to the original data of individual phase ages versus group phase ages, as can be seen from the formulas for the variances (5). If $\underline{a\theta} + \underline{c}$ is substituted for the quantities $\underline{t_c}$ in the formulas, the resulting expressions can be put into the form: variance $= A\theta^2 + B\theta + C$, which is the equation of a parabola. Because the general (parabolic) character of these curves is not determined by the original phase age data, but rather is introduced artificially by the method of fitting lines to these data, calculations of the variances were also made by a second method which used only the original data. These are not subject to the restrictions imposed by fitting straight lines, but suffer from the inclusion of random error which line-fitting tends to remove. The computations were done on the differences between the individual phase ages and the group phase ages, with results that are also given in Figure 3. It is seen that the two curves for variance among children are qualitatively the same, both rising throughout the entire range. The curves for the average variance within a child are somewhat different, since the minimum in the smooth curve (obtained from $\underline{a\theta} + \underline{c}$) at about 110 days is absent from the other. It appears, therefore, that the variance in the ages corresponding to a given achievement among children always increases with θ in the range considered (50 days to 220 days) whereas the average of variance within each child certainly increases for $\underline{\theta}$ greater than about 110 days, but has an uncertain behavior for smaller values.

The ratio of the variance among children to that within children, F, may now be calculated as a function of θ both from the values of $\underline{t_c}$ obtained from the constants $\underline{a}$ and $\underline{c}$ (first method) and from the original phase ages (second method). Although the curves of F, Fig. 3, calculated by the two methods are not identical, the difference between them is important in assessing their meaning. Consistently the magnitude of F, and hence its statistical significance, is greater when calculated from the constants $\underline{a}$ and $\underline{c}$; the greater values indicate that the method of fitting lines to the data has indeed been successful in removing random observational error. But the F curve obtained from the original phase ages increases steadily with advancing age and fails to show the maximum exhibited by the other curve; the steady increase suggests strongly that the terminal fall in the other curve is merely an obligatory result of the line-fitting technic and not an expression of true developmental happenings. By the first method the maximum value of F, attained at about a $\underline{\theta}$ of 150 days, is 8 and indicates far better differentiation of the individual from the group than was yielded by the constants $\underline{a}$ or $\underline{c}$. Also, correlation coefficients between achieve-

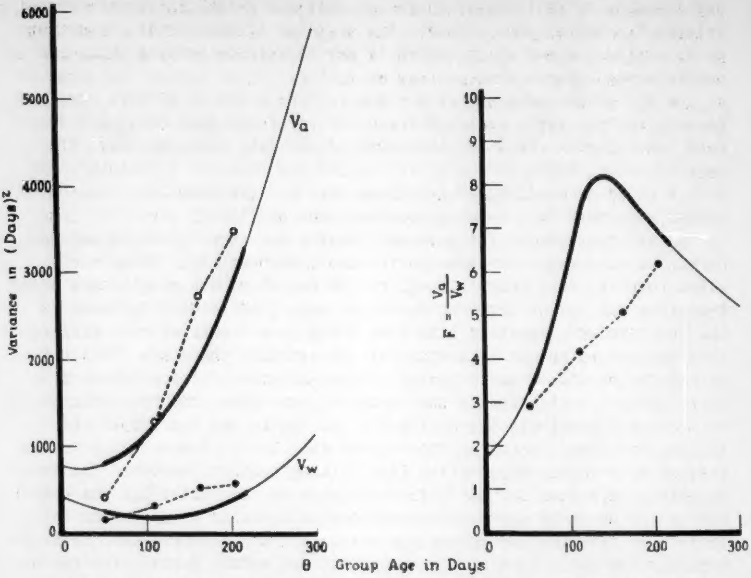

Fig. 3. Graphic representation of the relation between individual variance, V_w, and group variance, V_a, in achievement at various group ages. The dotted lines depict calculated values obtained directly from the original phase ages; the continuous lines show values computed from the linear equations relating individual age to group age.

ments in creeping and sitting, sitting and walking, and walking and creeping are considerably higher than are those for a and c, the largest being about +0.8.

It thus appears that for this age range at least the children are much better characterized in terms of their ages of achieving a certain stage of development than they are either by their (extrapolated) ages of attaining average group development at birth (c) or their relative rates of development (a). It follows that prediction from one activity to another is much more accurate if done in terms of achievement instead of in terms of age at zero development or of rate of development.

VI. COMPARISON OF TWINS AND NON-TWINS AND OF BOYS AND GIRLS

The analysis just described shows that the individual children are characterized by certain measures of development, that is, that the scatter of these measures among the different activities for one child is less than their scatter among different children. Thus, to some degree of accuracy, a child's developmental position, relative to other children may be determined. We may think of this information in terms of a list of the children arranged in order of decreasing speed of

development, or of increasing age of attaining a certain amount of development. Having thus arranged the children in rank order, we may try to determine whether or not there is any difference between twins and non-twins or between boys and girls.

Of the 40 children whose behavior is here studied, 26 were boys and 14 were girls. There were 5 pairs of twins of the same sex, only 1 pair being girls. Omitting instances of families composed only of a pair of twins, there were also in the group 3 families containing more than 1 child. Calculations are given here for the average of the behavior constants for creeping, sitting, and walking.

A pair of twins of the same sex, having the same or nearly the same heredity, and nearly the same environment, are certainly more nearly alike than are most pairs of children picked at random. In a rank order tabulation of the children according to some behavior constant, we should therefore expect to find that twins have a smaller rank difference than do most pairs of children. This is actually the case. Notice that in Figures 2A and 2C the unisexual twins, denoted by the numerals 1 to 5, are closer together than most pairs of children. The average rank difference for all possible pairs of children in any list of 40 is 13.67. For the constants $\underline{t}_c$ for a $\underline{\theta}$ of 150 days (the ages of achieving a state of development equal to that of the group at 150 days) the average rank difference for the unisexual twins is only 1.40; for the constants $\underline{a}$ (slopes or age equivalence constants) their average rank difference is 4.20; and for the constants $\underline{c}$ (age of achieving zero development), 8.40. We may determine whether the unisexual twins are significantly more alike than pairs of children picked at random by computing chi-square.[4] A 2 x 2 contingency table was used in this case, and Yates' correction (6) for cells containing less than 4 was applied. The probabilities that the observed distribution of twins could arise from random sampling from a population where twins are no more alike than children in general are: for $\underline{t}_c$ (θ = 150 days), 0.0001 per cent; for $\underline{a}$, 1.0 per cent; and for $\underline{c}$, over 10 per cent. The steps involved in arranging the data for this type of calculation will be clear from Table 2 which presents the analysis for $\underline{t}_c$ at a $\underline{\theta}$ of 150 days. It is clear that the order of significance for $\underline{t}_c$, $\underline{a}$, and $\underline{c}$ is the same as was found in the preceding section. The results therefore enhance the significance of the implications yielded by studying variance within and among children throughout the group.

No tests of significance were made using the three families available, but the average rank difference between members of the same family is for $\underline{t}_c$ ($\underline{\theta}$ = 150 days), 4.50; for $\underline{a}$, 9.67; and for $\underline{c}$, 8.67. Only the first of these numbers seems appreciably lower than the average value for all the children.

By means of the 2 x 2 contingency table one can also investigate whether twins on the average have a higher or a lower rank than other children, and whether girls have a higher or lower rank than boys. It was found that twins achieved the state of development represented by a $\underline{\theta}$ of 150 days later than other children (probability for $\underline{t}_c$ is 0.005

[4]*In the list of 40 children, there are 780 pairs. Of these, 39 differ by 1 in rank order, 38 differ by 2, 37 by 3, etc. There are 5 pairs of unisexual twins, and therefore 775 other pairs. From these data, the theoretical frequencies can immediately be calculated.*

TABLE 2

SAMPLE CONTINGENCY TABLE

	pairs of non-twins	pairs of twins	total pairs
pairs with rank diff. of one	35 (35.5)	4 (3.5)	39
pairs with rank diff. of more than one	740 (739.5)	1 (1.5)	741
total pairs	775	5	780

This table gives the distribution of the 780 different pairs in a group of 40 children when the children are arranged in order of increasing $\underline{t_c}$ (for $\underline{e} = 150$ days). The figures in parentheses are the frequencies after the application of Yates' correction. Chi-square is then given by:

$$\text{Chi-square} = \frac{[(739.5 \times 3.5) - (35.5 \times 1.5)]^2 \times 780}{775 \times 5 \times 39 \times 741} = 44.76$$

The probability that the result could have arisen by chance is less than 0.0001 per cent.

per cent), and that their rate of development might be slower (probability for $\underline{a}$ is 8.7 per cent). But no difference was found using the age of zero development, or $\underline{c}$. It is to be noted that the order of significance for the three measures is the same as that found previously.

No significant sex difference was found for $\underline{t_c}$ or for $\underline{a}$, but girls were shown to be ahead of boys at the time of birth (probability for $\underline{c}$ is 0.44 per cent). When the three activities, creeping, sitting, and walking, were analyzed separately rather than collectively, the girls were ahead of the boys in each instance (probabilities 3.2 per cent, 0.44 per cent, and 14 per cent, respectively). The evidence then is significant in suggesting that girls are more advanced than boys at birth. It will be remembered from the preceding section that the children are rather poorly characterized by $\underline{c}$. It appears now that such evidence of characterization of the individual as was found in the F analysis was due in part to the sex factor.

The results of this section, then, lend further support to the conclusion that the children are characterized by the measures of development discussed: quite well in terms of their ages of achieving a state of development equal to that of the group at 150 days, fairly well in terms of their relative rates of development, and rather poorly in terms of their ages of attaining average birth development. Also it

was found that in terms of the first two of these measures, unisexual twins are more nearly alike than other pairs of children, and that twins are behind other children at the group age of 150 days and develop slower. Finally, it appears that girls are ahead of boys at birth.

VII. COMMENT

To understand the import of this analysis of the interrelation among several behavior activities, it is necessary to hold in mind the relative nature of the comparisons. Since achievement in behavior is not something which can be measured in absolute units of development, it has been necessary to accept age or time as the basis for comparison. Now it is almost certain that development is never a linear function of time. A few weeks in the life of a very young infant may well be the equivalent in developmental change of several years later in childhood. It follows that sigmas or variances which might describe equal ranges of development, if absolute units were available, will, when expressed in time, be wholly different at different ages. For this reason developmental significance cannot be attached to the absolute values of the variances in the analysis which has been presented. We have seen that these variances fall into two groups, one which describes the consistency on the average within the individual child, and the other representing the scatter among different children. The former measures the extent to which individual performance in several activities (sitting, creeping, and walking) varies from that predicted for each activity from the approximately linear relationship between the individual and the group, and the latter describes the extent to which performance in the several activities collectively varies throughout the group. We have also seen that the significance of individual variance can be assessed in terms of the group variance, that is, by means of the variance ratio or F. Thus, in absolute terms one can never be sure that a child is becoming more or less consistent in his performance in several activities; one can never be certain whether or not a group of children are growing more or less alike in performance and achievement. But, if we are willing to accept group variability at each age as the standard for comparison, then the trend of the individual can be defined.

Throughout one part of the analysis we have been concerned chiefly with comparisons among and within 40 children in 3 activities. Statistically this part of the analysis has involved a total of 119 degrees of freedom of which 39 were available for determining variance throughout the group and 80 could be used for assessing the variance among the different activities. For these numbers of degrees of freedom the ratio F becomes significant (5 per cent level) at a value of 1.58 and highly significant (1 per cent level) at a value of 1.92. To the degree of certainty indicated by the probability integral such values demonstrate the presence of individualism in determining performance in several activities.

In another part of the analysis the search for individualism in the development of behavior was pursued by a wholly different technic of approach. Here the measuring rod of individualism was the similarity in performance between unisexual twins. It can scarcely be accidental

that the two methods of analysis yield essentially the same information.

The data which have been presented show that evidence of some influence characterizing the individual is present at birth or at least during the early weeks of life. The influence is, however, not very strong during this age of predominantly reflex behavior so that the scatter in performance by a single infant in different behaviors is almost as great as the scatter encountered among different infants. The degree of individualism at birth has been represented by an F of 1.74. As the infant grows older the value of F increases until at the age of about 150 days it has reached a maximum value of 8. By this time the infant is clearly differentiated as an individual; his performance in one of the activities provides a reasonably helpful estimate of performance to be expected in each of the other activities. From the standpoint of what has happened in development it is clear either that the coordinating influence which was barely discernible at birth has increased in strength or that a totally new coordinating influence has made its appearance. Although the curve of F with advancing age (Fig. 3) shows a decline after the age of 150 days, it was not possible by independent analysis of achievement at different ages to corroborate the decline. Moreover, it was shown that some decline in F was an obligatory result of the line-fitting technic used in analyzing the data. Consequently no proof has been found that individualism decreases after the rise which occurs during the early months. Such a decline may indeed take place at a time when opportunity, training, and attitude of the child tend to make performance in a favored activity run ahead of performance in less favored activities. At the moment, however, we have not discovered clear signs of the operation of such factors.

From the standpoint of the relation between overt behavior and development within the nervous system, the implications of the present analysis are clear. Reflex behavior during the early postnatal weeks is controlled chiefly by subcortical centers in the brain. The centers which relate to the reflexes involved in early sitting, creeping, and walking behavior are different and relatively independent. The small degree of association within individual infants which could be demonstrated can be attributed either to parallel development of different centers under identical environmental influence, to overlap between the centers and the several behaviors, or to an outside influence which exerts control over all of the centers. If the last possibility is true, it may be that even at this stage the cortical centers are beginning to function. In any case, as the infant grows older and as maturation in his cortex progresses, the influence which coordinates behavior becomes stronger. The circumstances allow one to think that the cortical centers themselves are the influence which leads to this change.

The associations or degrees of individualism which have been demonstrated are to be looked upon as a minimum representation of what actually exists. Precision of measurement is never possible when behavior is being observed; such precision, if it were attainable, could only operate to increase, never to decrease, the intensity of the associations. The analysis indicates that it is possible to divide achievement at any age into two components, status at birth and subsequent velocity of change. Both components have been identified and shown to

be statistically reliable. At the same time neither of the components separately can be used to provide a satisfactory measure for differentiating the individual from the group.

Finally, for those who are interested in establishing systems or scales for assessing the developmental status of infants, there are implications of importance. During the phase of reflex behavior individual performance in different activities varies so widely and so nearly coincides with the variability to be found in a group of infants that it scarcely seems possible to mark out any number of items for observation which can identify the individual with helpful accuracy. At later ages, particularly after the age of 3 months, the attempts will be attended by a measure of success. The practicability of preparing such a developmental yardstick is visualized clearly in the portion of the analysis dealing with the rank order of twins in the group. Thus, when the 40 children were arranged in order according to average achievement at 150 days, 4 out of 5 of the unisexual twins occupied adjacent positions; the fifth pair of twins were separated by only 2 children.

VIII. SUMMARY

Longitudinal data on the development of behavior in children, collected by the staff of the Normal Child Development Study over a period of 4 years, have been subjected to mathematical and statistical analysis in order to assess the extent to which the individual child can be identified within and differentiated from a group of his peers. The data deal for the most part with serial observations on 40 children who include 5 sets of unisexual twins; the observations began during early postnatal life and continued through the sequential developmental phases leading to mature behavior in the activities of sitting, creeping, walking, reaching for a lure, and reacting to the prick of a pin.

It is shown that achievement in any activity at any of the ages studied can be resolved into two components, status at birth and subsequent rate of change. For each child in each activity not only the components but also achievement itself at sequential ages can be assigned numerical values which locate the position of the child against the background furnished by all of the children in the same activity. These numerical values or measures of development represent the data subjected to analysis.

The analysis has been made by two methods which utilize wholly independent properties of the data. For each method the statistical reliability of the measures in identifying the individual has been determined; the fact that both methods yield the same relative order of fidelity of the measures enhances the significance of the results. By the first method the variability of each child throughout the several activities was assessed in terms of the variability throughout the group of children. In the second method similar measures for each child in the several activities were averaged and the average values were arranged in rank order of magnitude; the faithfulness of the measures in characterizing the individual was then determined by the relative position of twins in the rank order scale.

The results indicate that on the basis of behavior the individual is

rather poorly differentiated from the group at the time of birth. Since it is also shown that girls are in advance of boys at birth, some of the slight degree of differentiation which was demonstrated may represent the contribution of the sex factor. In terms of rate of change in development (velocity of approach to average mature behavior), the individual is differentiated from the group with somewhat higher precision; nevertheless, the degree of differentiation is not great enough to provide a satisfactory means of characterizing the individual. When achievement itself, rather than its components, is taken as the measure of development, the results show that the individual is more and more sharply differentiated from the group up to the age of 150 days. At this age a rank order of arrangement of the 40 children disclosed twins in adjacent positions in four out of five instances; in the fifth instance the twins were separated by two other children. The data did not permit conclusions beyond the age of 150 days.

On the average twins develop more slowly in the behavior activities than do other children.

The progressive differentiation of the individual with advancing age suggests the development of centers in the nervous system which act to coordinate activity in the several forms of behavior. The circumstances permit the interpretation that development of the cerebral cortex is the factor which leads to the coordination.

The data render it unlikely that scales based on achievement in behavior can yield satisfactory appraisals of the individual under the age of about 3 months. At later ages such scales, if carefully made, can be expected with confidence to provide increasingly accurate means of assessing individual attainment.

APPENDICES

Appendix A. Calculation of the phase ages.

The phase age is computed by averaging all of the ages at which a plus rating is recorded for the phase in question. Let the successive ages at which observations were made be denoted by T_1, T_2, T_3,.....T_n.. ..... The simplest formula for the average age is:

$$t \text{ (average age)} = \frac{1}{N}\Sigma T_n$$

where the summation is to be taken over all T_n for which a plus is recorded, and N is the total number of such T_n.

This formula was corrected in two ways to take account of the unequal spacing of the observations in time. First, each observation was weighted according to the time interval between the preceding and following observations which might be either plus or minus; specifically, the nth observation was given the relative weight $(T_{n+1} - T_{n-1})$. Second, in order to avoid undue influence from extreme deviations, the ages to be averaged were taken as the $\frac{1}{4}(T_{n+1} + 2T_n + T_{n-1})$. Thus the formula used is:

$$t\text{(average age)} = \frac{\Sigma(T_{n+1} - T_{n-1})\,(T_{n+1} + 2T_n + T_{n-1})}{4\,\Sigma\ (T_{n+1} - T_{n-1})}$$

Here the summation is again to be taken over all values of n for which a plus is recorded.

Appendix B. Method of fitting lines.

To shorten the calculations, a method of averages was used for the curve fitting instead of least squares. The equation to be fitted is

$$t_c = a\theta + c$$

where a and c are the constants to be determined. The points were divided into two groups, one containing points with values of θ larger than the median value, the other containing points with θ smaller. Thus N_1, the number of points in one group, was either equal to N_2, or differed from it by unity. Next the "center of gravity" of each group was determined, and the line calculated to pass through these two points. The coordinates of the "centers of gravity" of the two groups are given by:

$$\bar{\theta}_1 = \frac{1}{N_1}\Sigma\theta_1 \qquad \bar{\theta}_2 = \frac{1}{N_2}\Sigma\theta_2$$

$$\bar{t}_1 = \frac{1}{N_1}\Sigma t_1 \qquad \bar{t}_2 = \frac{1}{N_2}\Sigma t_2$$

The values of a and c for a line passing through these two points are:

$$a = \frac{\bar{t}_2 - \bar{t}_1}{\bar{\theta}_2 - \bar{\theta}_1} = \frac{N_1\Sigma t_2 - N_2\Sigma t_1}{N_1\Sigma\theta_2 - N_2\Sigma\theta_1}$$

$$c = \bar{t}_1 - a\bar{\theta}_1 = \frac{1}{N_1}(\Sigma t_1 - a\Sigma\theta_1)$$

Appendix C. It is desired to show that the constant $\underline{a}$ is the ratio of the average rate of development in the group to that of the individual. Suppose that a quantitative measure of development $\underline{y}$ has been obtained for a certain activity. Then we may determine the change of $\underline{y}$ with age for some individual child, and also for the group as a whole. By fitting equations to these data we can then obtain $\underline{y}$ as a function of $\underline{t_c}$ (individual's age) and as a function of $\underline{\theta}$ (group age). From these two functional relationships, the rate of development of $\underline{y}$ for the individual can be computed as the first derivative $\frac{dy}{dt}$; and the rate of development of $\underline{y}$ for the group, as the derivative $\frac{dy}{d\theta}$. The ratio of the rate of development for the group to that for the individual then becomes:

$$\frac{\text{group rate}}{\text{individual rate}} = \frac{\frac{dy}{d\theta}}{\frac{dy}{dt_c}} = \frac{dy}{d\theta} \cdot \frac{dt_c}{dy} = \frac{dt_c}{d\theta}$$

But we have already found empirically a relation between $\underline{t_c}$ and $\underline{\theta}$ for each activity, namely

$$t_c = a\theta + c$$

From this equation $\frac{dt_c}{d\theta}$, the rate of change of $\underline{t_c}$ with $\underline{\theta}$, can also be calculated. Evidently:

$$\frac{dt_c}{d\theta} = a$$

and hence

$$a = \frac{\text{group rate}}{\text{individual rate}}$$

which we desired to prove.

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THE RELATION BETWEEN THE DEVELOPMENT OF BEHAVIOR AND THE PATTERN OF PHYSICAL GROWTH[1]

A. A. WEECH AND R. V. D. CAMPBELL

It is commonly believed that a relationship exists between rate of growth in body weight and achievement in such behaviors as creeping, sitting, and walking. The infant who grows rapidly is apt to be slow in behavior achievement and conversely the infant who grows slowly is likely to progress rapidly in the acquisition of motor performance. The quantitative measures of development in behavior described in a previous paper (1) have provided a convenient means of testing the validity of the belief. In the present paper it will be shown that the correlations between behavior and a function of body weight which measures the rate of gain are high; they are high enough to suggest that the significance of individual achievement in behavior can be assessed more accurately if consideration is given to the past record of the infant with respect to gain in weight.

The analysis of development in behavior (1) dealt with 40 infants. Records of body weight had been made with sufficient frequency to permit the drawing of a smoothed weight curve for 33 of them. From each infant's curve the body weight at 50 days and at 150 days was obtained. The first of these points was selected because at younger ages the weight data were incomplete; the second point was chosen because at the age of 150 days the measures of achievement in behavior attained their maximum significance. The body weight at 50 days was used directly in the correlations with behavior; examination of the data from a smaller number of the infants suggests that the results would have been essentially the same if it had been possible to use birth weight in this part of the analysis. From the weight at 50 days and the weight at 150 days the percentage gain in weight was computed for each of the 33 infants. The percentage increase in weight is a more accurate measure of the basic cellular multiplication which characterizes growth than is the actual gain in pounds and ounces. Accordingly, it was used in the correlations with behavior.

In the previous paper on the development of behavior it was shown that the individual infant was differentiated from the group better in terms of his achievement at 150 days than by any of the other measures available for study. This measure of behavior development, calculated as $\underline{t}_c$ for a $\underline{\theta}$ of 150 days (1), was used for the first correlations with growth in mass. If achievement in behavior at 150 days is represented by A, body weight at 50 days by W, and percentage gain in weight by G, the relationships in terms of coefficients of correlation, $\underline{r}$, with the standard errors,[2] were found to be as follows:

$$\underline{r}_{AW} = -0.678 \pm 0.097$$

$$\underline{r}_{AG} = +0.687 \pm 0.038$$

[1] *From the Normal Child Development Study of the Department of Pediatrics, Columbia University and the Babies Hospital.*

[2] *The error of the correlation coefficient was computed for the simple $\underline{r}$'s as $(1-r^2) \div \sqrt{N-2}$ and for the partial $\underline{r}$'s as $(1-r^2) \div \sqrt{N-3}$.*

CHILD DEVELOPMENT, Vol. 12, No. 3 (September, 1941)

Both of the correlation r's are highly significant. In interpreting their meaning it is necessary to remember that t_c refers to the age at which a standard degree of achievement was acquired; therefore, a high value for A means slow development in behavior and a low A indicates rapid development. The negative correlation between A and W signifies that the infants who were heavy at 50 days were on the average more advanced in motor development at 150 days than were infants who were light. The positive correlation between A and G means that the infants who showed large percentage gains in weight were in general slower in achieving motor performance than the infants who grew at a slower rate.

It is clear, however, that W and G are not independent variables. G was computed as the percentage increase in W and in general it is true that infants who are heavy at 50 days will show smaller percentage gains than infants who are light. This fact is expressed by a negative coefficient of correlation between W and G:

$$r_{WG} = -0.673 \pm 0.098$$

The association between W and G is also highly significant and so must be considered in interpreting the relations between A and W and between A and G. The results of partial correlations which exclude the influence of the relationship between W and G follow:

$$r_{AW.G} = -0.283 \pm 0.168$$

$$r_{AG.W} = +0.793 \pm 0.068$$

From the first of the partial correlations it appears that the association between achievement in behavior and weight at 50 days is not significant when subsequent gains in weight are equal; the significant association found by simple correlation was an indirect expression of the relation between weight at 50 days and subsequent percentage gain. On the other hand, the second of the partial correlations remains highly significant and justifies belief in an inverse relationship between achievement in behavior and rate of increase in weight.

The measures of growth in mass, W and G, were also correlated with a. The constant a, fully described in the previous paper (1) is a value which expresses the rate of change in the development of behavior and may be looked upon as one of the components which lead to achievement at any designated age. All of the r's and partial r's were somewhat lower than when achievement at 150 days was the measure of behavior development. However, since the order of significance for the two sets of values is identical and since identical conclusions are to be drawn therefrom, we shall merely tabulate the results.

$$r_{aW} = -0.570 \pm 0.121$$

$$r_{aG} = +0.695 \pm 0.093$$

$$r_{aW.G} = -0.192 \pm 0.176$$

$$r_{aG.W} = +0.513 \pm 0.134$$

DISCUSSION

The foregoing analysis, which demonstrates for the infant an inverse relationship between percentage gain in weight and achievement in such motor performances as sitting, creeping, and walking, has important

implications for those who wish to assess the meaning of advancement or retardation in achievement as exhibited by individual infants. In the absence of contrary evidence, it appears unlikely that divergence in achievement which results solely from the pattern of physical growth can have predictive value concerning the child's ultimate ability either in motor coordination or in intellectual accomplishment. The correlation between achievement in behavior at 150 days and the measure of physical growth, G, was expressed by a coefficient of 0.887. A correlation r of this magnitude means that more than half (54 per cent) of the scatter in performance of a group of infants can be accounted for if the past records with respect to gain in weight are known. By taking into account the gain in weight, regression equations can be constructed to compute for each infant at any age the extent of achievement in behavior to be expected for his own particular growth pattern. It may well be that divergence from such computed achievement will constitute a more sensitive yardstick of the potentiality for development in the future than mere achievement itself.

Although the intensive longitudinal observations on behavior which have been accumulated by the staff of the Normal Child Development Study[3] are peculiarly suited to elucidating the relationships described in this paper and in the previous paper (1), they do not represent the type of data from which useful norms of achievement can be prepared. The phase ages in each activity, which have constituted the units of measure, were determined with relative accuracy only by long continued observations on each child. In general, observations of this type will not be available when assessments of achievement in behavior are wanted. The practical scale should make it possible to provide a rating after one or at most a few periods of observation. To eliminate random error such a scale would have to include observations on many more activities than have been used in these analyses.

SUMMARY

Quantitative measures of the development of 33 infants in such behaviors as sitting, creeping, and walking have been correlated with the body weights of the infants at 50 days and with the percentage increases in weight during the age period from 50 to 150 days.

A significant correlation coefficient between behavior development and weight at 50 days indicates that infants at this age who are relatively heavy develop more rapidly in behavior than do infants who are relatively light. A significant correlation coefficient between behavior development and the percentage increase in weight indicates that the infant who is expanding rapidly in physical size develops on the average more slowly in behavior than does the infant with a slow rate of gain.

By partial correlation it is demonstrated that the relationship between weight at 50 days and behavior development is not a direct one of cause and effect. Infants who are large at 50 days show a small subse-

[3]*The observations are the result of the indefatigable effort of Dr. Myrtle B. McGraw. It is a pleasure to express to her our thanks for data which have made these analyses possible.*

quent rate of gain; infants who are small at 50 days exhibit large subsequent gains. When the influence of the association between weight at 50 days and rate of gain during ensuing months is excluded by partial correlation, the coefficient describing the relationship between weight at 50 days and behavior development is not significant. On the other hand, the association between percentage gain in weight and behavior development remains significant even when the effect of variations in weight at 50 days is excluded by partial correlation.

It is suggested that the association between development in behavior and the pattern of physical growth should be of importance in attempts to assess the significance of individual advancement or retardation in the development of behavior.

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DEVELOPMENTAL CHANGES IN ATTITUDE AS ONE FACTOR DETERMINING ENERGY OUTPUT IN A MOTOR PERFORMANCE[1]

VERA T. DAMMANN

This paper is the outcome of incidental observations made over a period of 3 years in connection with a study of "the time and power relations for a human infant climbing inclines of various slopes." The results of the study were reported by Weinbach (1) in one of a series of contributions designed to illustrate the possibility of fitting growth equations to physiological phenomena. Weinbach considered that the purpose of the studies was to try "to state in physical language, using concepts already established, the properties of the growing organism as exemplified by changes taking place with advancing time." This particular study was of a motor-learning situation, based on an observation made by McGraw (2), in the course of a study of development in twins. She had observed that a complicated learning pattern could be grafted onto the characteristic creeping behavior of the human infant. By increasing the angle of the slope she was able to teach a creeping infant to ascend inclines as steep as 70°. Weinbach subsequently selected this motor-learning situation as one which would lend itself to study in terms of theoretical growth equations.

One child, Jimmy Briggs, from the age of 8 months on, (the age at which he began to creep), was given daily tests 5 days a week of his ability to creep up a wooden slide 6 feet long, which was clamped successively to 7 stools of graded heights, thus forming inclines of roughly the following angles: 10°, 17°, 23°, 30°, 38°, 47°, 59°. The procedure was to place the child at the bottom of the lowest incline and induce him by means of a lure to creep to the top. The time he took in the ascent was clocked with a stop watch. The slide was then clamped to the next stool and he was placed at the bottom of it. This procedure was continued until he failed to go up one of the inclines, whereupon the activity was stopped until the next day. The age and weight of the child were recorded at the time of each testing. The times of ascent of each of the various slides were plotted against age and the data fitted to a theoretically derived growth equation from which the velocity constant of growth in per cent per day and the acceleration of growth, et cetera, could be evaluated. The power output in climbing the slides was determined and the curve of power output versus age was plotted. These data have been published in the report by Weinbach (1). Records on Jimmy Briggs were continued until he was past 3½ years old. Recordings are still being taken on Jimmy Briggs at fortnightly intervals, and the same observations have been carried out on 2 girl infants, Jane Woods and Patsy Shelley. They were tested 5 days a week up to the ages of 25 months and 20 months respectively; subsequently they have been tested only twice weekly.

Weinbach was able, by isolating for measurement the above objective and quantitative elements from the total behavior, to express this motor-learning pattern in terms of power output and to show a definite

[1] *From the Normal Child Development Study of the Department of Pediatrics, Columbia University, and the Babies Hospital.*

CHILD DEVELOPMENT, Vol. 12, No. 3 (September, 1941)

growth trend. However, during the course of collecting the data, qualitative factors which influenced the objective measurements were observed. Such factors could not be recorded quantitatively or taken into consideration in the time-power calculations. Because they are an integral part of the growth phenomenon and did undoubtedly influence the objective measurements to some extent, it has been considered worthwhile to give some account to them here.

The chief qualitative factor influencing the data was that of changes in attitude of the child towards the slide-climbing situation. Although the observations were made on only 3 children, the study was an intensive one, comprising in all 879 observations. When the same distinct developmental sequence was found in the attitude of all 3 children despite widely divergent temperamental make-up and physical type, it was considered justifiable to generalize and consider the changes in attitude not as individual idiosyncrasies but as general developmental factors which would influence any such motor-learning situation during the first 3 years of life. For convenience of discussion, typical changes in attitude have been classified into developmental phases.

The classification of the changes in attitude into phases was somewhat arbitrary, since there was no clear division between disappearance and emergence. Each phase contained elements of the preceding and the following phases, and the merging of the one into the other was almost impossible to detect. Nevertheless, when the total picture was considered, changes in attitude seemed to fall roughly into the following five categories.

1. In the very young infant just learning to creep it was not only lack of coordination and the difficulty of the motor task which made for poor time in creeping up the slides. The baby beginning to creep had only a short attention span and was very easily distracted. His interest in the environment was diffuse and a specific object intended to lure him up the slide had not much greater attraction than any other object in the new universe he was just beginning to explore under his own power. A knot in the wood on the surface of the slide, a tiny speck of dust, a scratch in the varnish, were sufficient to distract his attention and cause him to pause for a few seconds to investigate before continuing. During this first stage, therefore, diffusion of interest and great distractability frequently added many seconds to the time of ascent.

2. The second stage emerged as one in which the child's interest in the environment had become considerably less diffuse. At this time he showed particular and intense interest in specific objects, particularly those which he was able to manipulate, and he would struggle passionately to obtain them. During this stage the motor performance was usually enhanced by the attitude, since the infant would tax his motor capacities to the utmost in order to obtain the object used to lure him to the top of the slide. There were occasions, however, when the strong urge to obtain the lure impeded motor performance. On the higher inclines, when the motor task was more difficult and not completely mastered, the child would engage in diffuse activity during the ascent; frequently slipping back because in overeagerness to reach the top he did not put enough pressure on his palms or push adequately with his toes, or he

would raise his head and shoulders to see the object at the top of the slide and thus shift his center of gravity and slip back to the bottom. At times this over-stimulation from the lure completely blocked performance and the child remained at the bottom of the slide, alternately reaching towards the lure, slapping the surface, jigging up and down excitedly and vociferating his desire. Such behavior meant that a failure was recorded on inclines which the child was actually able to ascend.[2]

3. The third phase in attitude which emerged imperceptibly from the second was one in which the whole situation - the placing of the lure, the ascent of the slide, the clamping of the slide to the next graded stool and so forth - became ordered into a definite Gestalt in the child's mind. It was possible to see this Gestalt being gradually built up. While in the earlier stages, the experimenter would have to take the lure out of the child's hand in order to place it at the top of the next slide, now he would participate in preparation for the next performance. At first this participation was simple. After the child crept up one slide for the lure, he would play on the floor with it while the experimenter clamped the slide to the next stool. But when she approached, he would spontaneously hold it out to be placed on top of the stool. Then he would proceed in a matter of fact way to creep up to get it again. A little later, after playing with the lure while the slide was being clamped into place, he would run of his own accord to place it on top, sometimes asking to be lifted up in order to do so. An extreme instance of this attitude was manifested one day by Jane Woods at the age of 22 months, who, with considerable difficulty, climbed up the incline of 47° with the lure (a 5-inch-long toy automobile) in one hand, placed it on top of the stool, slid down to the bottom and then proceeded to creep up again to get it. That the lure was still an essential part of the situation, however, was indicated by the fact that any of the three children would refuse to go up until the lure was in place, or, if it accidentally got knocked off, would wait poised in mid-slide until it was replaced.

4. The next stage was a good example of Professor Woodworth's (3) contention that mechanisms may become drives. The child went up the inclines for the sheer satisfaction of performing the motor act, and it was during this period that he put out his optimum performance. The method was well integrated and the times of ascent were at their lowest. According to Weinbach, the child's body proportions around this time are best fitted to the motor task of climbing these inclines. Body build may, therefore, have been one reason that the best performance was given during this period, but it is also likely that pleasure in the activity contributed to the excellence of performance. At this time the children frequently went up and down each slide several times. The following is a note on Jimmy Briggs' general attitude made during the period when he

[2]McGraw (2) has pointed out the disturbing effect of an eager cooperative attitude even in the behavior of younger infants, (p. 285) "When there is an undue attitude of receptivity and cooperation, the somatic performance is likely to become diffuse and generalized. This principle is well illustrated in the behavior of the baby who is just beginning to extend his arms to reach for an object in the visual field. If the sight of the object is excessively stimulating, the energy which should be directed toward extension of the arm in the direction of the object becomes converted into disorganized general body activity. It is desirable that the individual should be interested in the object just enough to elicit a well-controlled motor act. Too little interest would fail to stimulate a movement in the direction of the object, and too much interest would interfere with the individual's control over the motor activity involved."

was 23 to 24 months old:

> "During the whole of this month he has shown great joy in the slide situation. There is no need to use any sort of lure even on the higher slides. He runs to creep up them as soon as he enters the room. He generally runs to the door of the laboratory as soon as he sees the experimenter coming, crying 'Slides! Slides!' Sometimes he is so eager to go up that he starts before the experimenter has had time to clamp the slide firmly to the next stool, and then he will stand up again and ask 'Ready? Ready?'"

5. Finally there came the stage when performance was more or less dependent on mood. The motor task had been completely mastered and had lost its fascination. The performance was gone through as one of the usual laboratory routines, almost always cooperatively but not with the same zest. In this final stage, as in the earliest, the child was easily distracted, not because he was over-stimulated by the environment, but because he was bored with the situation and sought diversion in the environment. To relieve the monotony he would try variations on his usual method of going up. He tried to go up the steeper inclines on his hands and knees (instead of hands and feet); he crept up the lower ones on his hands and feet looking through his legs; he started walking up, then dropped to his knees, then got upright again and tried to finish walking up. A motor horn heard from the street or a baby crying in the nursery caused him to pause and comment, or he tried to distract the experimenter's attention from the situation by engaging her in conversation about extraneous matters. Weinbach desired the experiment to be continued on Jimmy Briggs until such time as changes in bodily proportions rendered it impossible for him to ascend the higher inclines. Now, at 3½ years of age, it is already more difficult for him, but the wide scatter in his times of ascent at the present is also to a very large extent attributable to the variability of his attitude. He can still go up in his minimum time if he happens to be interested enough.

It is, unfortunately, not possible to present the various changes in attitude in the form of curves for comparison with the curves of time-power relations produced by Weinbach. Since the original purpose of the experiment was to isolate and measure the quantitative factors described at the beginning, observations on attitude were merely incidental and were not kept systematically. Moreover, since the major condition for optimum motor performance was to keep the child's attitude towards the task one of interest and cooperation, the procedure was modified whenever possible to fit the changes in attitude. Often the child was tested several times until a way of obtaining a good performance had been found. Consequently, the wide divergences caused by attitudinal factors do not show up in the finally recorded data. For example, during the first few months if the child paused to examine a knot in the wood or for some similar reason stopped in the middle of the ascent, the length of the pause was measured by a second stop watch and deducted from the total time of ascent. Or, if during the second stage the child was overstimulated by the lure and took a long time in

an ascent through slipping and sliding in his overeagerness to reach the top, he would be given another trial when his excitement had subsided sufficiently to allow a normal performance. Similarly the times of ascent were not recorded in the final stages when through boredom the child went up by some more awkward method than usual.

These observations furnish a good illustration of the fallacy of keeping experimental conditions rigidly uniform when working with children. In this case a rigidly consistent method of inducing the child to creep up the inclines would have defeated the object of the experiment, which was to produce the optimum motor performance of which the child was capable at the time of testing. Naturally, uniform procedure as regards the angles of the inclines, the order of presenting them, the method of recording the time of ascent, et cetera, was maintained. But quite early in the experiment, it was decided that keeping the "lure" constant would be a detrimental rather than a contributing factor towards keeping conditions constant. So far as lure was concerned, therefore, it was varied to meet the changes in attitude. In the first phase, the lure was a brightly colored rattle or bell held just beyond the infant's reach and while being moved along in front of him, shaken vigorously all the time in order to crowd out distracting stimuli. A lure on the top of the slide while he was at the bottom would have been too remote to act as a stimulus. In the second stage, when the child was passionately interested in objects, it was found best to use as a lure any object on which the attention happened to be fixed at the moment - a pencil, a shoe, or a sock, if he appeared more interested in them than in the official lure. During the next stage, when the whole situation had become a Gestalt, the choice of lure was not important so long as there was a lure of some sort. In the following stage of intense satisfaction in the motor activity for its own sake, often no lure was necessary. In the final stage, incentive was again extremely important, and frequently the resourcefulness of the experimenter was taxed to find ways of interesting the subject in the now monotonous routine of climbing up the slides. Sometimes a candy lure would be satisfactory; sometimes the incentive of a more novel motor task served the purpose - for example, Jimmy Briggs sometimes climbed up in order to try running down backwards on the lower inclines and upright on the higher inclines; Jane Woods on days when she was completely bored was sometimes induced to give an excellent performance by bringing in a spectator as she was responsive to an audience.

It is clear from these observations that the slide-climbing situation could be used as a technic for recording an entirely different series of developmental characteristics from those for which the situation was originally devised. It is likely that these characteristics of attitude, even though not capable of being recorded in mensurable units, are just as important to an understanding of growth as the features which so far have been analyzed.

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SIZE DISCRIMINATION IN CHILDREN[1]

LOUIS LONG

A complete analysis of the perceptual ability of children must eventually include the concept of size. The present report concerns an experiment which was designed to investigate some factors that might be effective in size discrimination. At present there is a certain amount of data available on the accuracy of size discrimination (1, 3, 4), but in previous work a single geometrical shape has been used in measuring this ability. The aim of the present paper is to present data that will make it possible to study size discrimination ability and its relation to the shape of the discriminated figures which were, for the purposes of this experiment, regular geometrical forms. The hypothesis under investigation can be stated in the following manner: size discrimination is independent of the geometrical shape of the stimuli. Can a child, in other words, discriminate between circles just as efficiently as he can between squares? This hypothesis may, for convenience, be broken down into several specific experimental problems, or sub-hypotheses. The first involves a comparison of the rapidity with which initial responses can be set up to the larger of two figures of the same geometrical shape. If size discrimination is independent of shape it follows that this discrimination will be learned just as readily for one shape as for another. In the second problem the accuracy of the discrimination of the larger of two figures of one shape was compared with the accuracy of the discrimination of the larger of two figures of another shape. In this instance it is to be expected from the hypothesis that the number of errors made in selecting the larger of two geometrical figures of the same shape will be approximately the same for all shapes. The third problem involves a comparison of the results of two different types of discriminations. In one case the child was to select the larger of two figures differing in shape, in the other the child was to select the larger of two figures of the same shape. The accuracy of the responses in the two situations should not differ significantly, if the hypothesis is correct.

Apparatus

The apparatus consisted of two identical and interchangeable compartments in which the figures used as stimuli were placed. The front of each compartment is a one-way mirror screen, which becomes transparent when the illumination is greater inside the box than outside. The base, to which the compartments are attached, contains two holes centered directly below the middle of each compartment. Candy rolls out of these holes into small receptacles. The child responds by pressing the mirror of the compartment. Pressure on the mirror causes the lights inside the box to turn off and the electric clock to stop. If the mirror of the box which contains the positive stimulus is pushed, a motor disc system is energized and a pellet of candy is delivered. If the response

[1]*From the Normal Child Development Study of the Department of Diseases of Children, Columbia University, and the Babies Hospital.*

The assistance of Miss Kathleen Farmer is gratefully acknowledged.

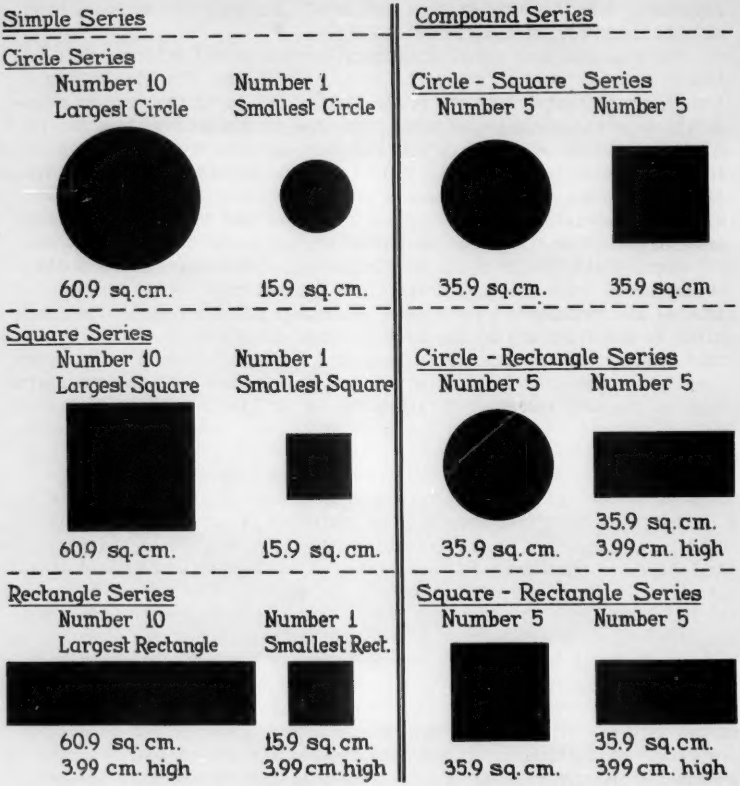

Fig. 1. Examples of the pairs of stimuli.

is made to the negative stimulus, the motor disc system is not energized and no candy is delivered. The apparatus is constructed so that candy may be received from either compartment. The throwing of a switch determines the positive box. This same switch turns the lights on inside the compartments and starts the clock. A more complete description of the apparatus and its advantages will be found elsewhere (2).

Procedure and Stimuli

The child is brought into the room and seated before the apparatus. The experimenter then goes behind the curtain and remains there until the end of the session. The lights are turned on, exposing the objects in the compartments. The child's reactions are noted through a one-way mirror. No instructions other than "get the candy" are given. All of the children of this experiment were used in the roundness situation (2). Consequently they have on previous occasions made the appropriate

response. Some few subjects did not recall the response at once, but all discovered it without assistance.

The children were tested on Monday, Wednesday and Friday. This schedule was adhered to except in cases of illness. The time of day for the experimental sessions varied from child to child, but was relatively constant for any one child. No attempt was made to keep the number of trials per day constant since it has been found that motivation and cooperation vary greatly from day to day. A maximum number of trials (40) for any one day was, however, set up. Below this maximum, the number of trials for any one day was determined by the child's willingness to cooperate. The average number of trials per day was about 25.

The stimuli consisted of two-dimensional black figures on a white background. Three types of geometrical figures were used: circle, square, and rectangle. There were 10 figures of each shape. The dimensions of the figures are presented in Table 1. It is important to notice that the series were planned so that each figure of a series would correspond in size with the figures of the other series. A constant increment (5 sq. cm.) between the figures of any one series was maintained.

Table 1

AREA OF FIGURES IN SQUARE CENTIMETERS

Number of Figure in Series	Circle	Square	Rectangle
1	16	16	16
2	21	20	21
3	26	26	25
4	31	31	31
5	36	36	35
6	41	41	41
7	46	45	46
8	51	51	51
9	56	56	56
10	61	61	61

(The slight irregularity indicated in Table 1 is due to calculating and drawing inaccuracies.) There is practically a 1 : 2 : 4 relationship between figure numbers 1, 4, and 10. (See Fig. 1 for typical stimuli.)

The children were trained on the largest and smallest stimuli of one series. A response to the former was rewarded, whereas the reward was withheld when a response was made to the latter. After the criterion of 20 consecutive responses to the positive training stimulus was fulfilled the other figures of the same geometrical shape were interpaired with each other, making in all 45 differing combinations. The other series of figures were then presented. Thus there were three series (circle, square, and rectangle) in which the discrimination involved the selection of the larger of two figures of the <u>same</u> shape (referred to hereafter as "simple series"). In the next series the task was the selection of the larger of two figures of <u>different</u> shapes. The stimuli of the three "simple series" were paired with each other to form the "compound series". For example, each figure of the circle series was paired once with each figure of the square series. The simple series

were always presented before the compound ones, but the order in which the various simple and complex series were presented was randomized from child to child. (The actual order is presented in Table 2.) The order within any one series was also randomized.

Table 2

ORDER OF PRESENTATION OF SERIES

Subjects	Circle	Square	Rectangle	C-S	C-R	S-R
ED	3*	2	1	4	6	5**
AR	2	1	3	5	4	6
JC	2	1	3	6	5	4**
TP	3	1	2	5	6	4
LD	2	3	1	5	4	6
CC	1	2	3	4	5	6
BB	1	2	3	6	5	4
FM	3	2	1	6	4	5
MM	3	1	2	5	6	4
MW	1	3	2	4	5	6
MH	2	3	1	4	6	5
AD	1	3	2	6	4	5
Number of Trials in Each	45	45	45	100	100	100

* 3 means this series was the third one presented to this child.
** Failed to learn the initial discrimination.

Ten subjects learned the initial discrimination. They varied in age from 4 years 2 months to 7 years 2 months. Some general information about the subjects is presented in Table 3. Data from 12 subjects were to have been utilized, but two subjects failed to learn the initial task in 500 trials. These two subjects are listed in Table 2 merely to show the original plan of the order of presentation of the series.

Table 3

AGE, SEX, INTELLIGENCE QUOTIENT AND LENGTH OF EXPERIMENTAL PERIOD OF SUBJECTS

		Interval of Experiment		Age at Midpoint of Experiment		
Subjects	Sex	Months	Days	Years	Months	IQ
AR	M	1	16	4	2	120
TP	M	1	18	5	6	124
LD	M	1	23	5	10	106
CC	F	1	15	6	1	127
BB	F	1	20	6	2	131
FM	F	1	28	6	4	96
MM	F	3	21	6	5	101
MW	F	1	13	6	6	98
MH	F	3	25	7	2	109
AD	M	0	28	7	2	126

Results

The number of trials taken by each child in learning the initial discrimination is presented in Table 4. The variations from subject to subject are so large that it is impossible to use these data to study the relationship between the number of trials and the different

Table 4

NUMBER OF TRIALS FOR ESTABLISHMENT OF INITIAL RESPONSE

Circle		Series Square		Rectangle	
Subjects	Number of Trials*	Subjects	Number of Trials*	Subjects	Number of Trials*
BB	17	AR	8	LD	356
CC	5	TP	5	FM	7
MW	11	MM	437	MH	9
AD	16				

*20 consecutive responses to positive stimulus are omitted.

geometrical shapes. The variation is undoubtedly due to individual differences rather than to the shape presented.

The number of correct responses made by each child in the series with circles, squares, or rectangles as stimuli is presented in Table 5. It will be seen that the subjects generalized from the initial training and selected the larger of the two stimuli on practically every trial. The lowest score was 40 responses to the positive stimulus in 45 trials. An inspection of Table 5 suggests that the accuracy of the child's discrimination is not affected by the shape of the stimuli. The slight variation between the means of the series was found to be unreliable and the fluctuations can safely be attributed to chance. The variation between subjects was found to be slightly greater than the variation from series to series.

Table 5

NUMBER OF CORRECT RESPONSES FOR CIRCLE, SQUARE, AND RECTANGLE SERIES

Subjects	Number of Correct Responses* Series Circle	Square	Rectangle	Average	Per cent of Correct Responses
AR	44	42	41	42.3	94.1
TP	43	43	44	43.3	96.3
LD	45	45	40	43.3	96.3
CC	41	45	45	43.7	97.0
BB	44	43	42	43.0	95.6
FM	44	44	45	44.3	98.5
MM	44	45	45	44.7	99.3
MW	40	45	45	43.3	96.3
MH	44	43	43	43.3	96.3
AD	45	45	44	44.7	99.3
Averages	43.4	44.0	43.4		

*45 trials in each series.
Order of presentation of series is disregarded in this table.

A similar analysis was made of the data from the compound series, where figures of different geometrical shapes were paired. Table 6 shows that more errors were made in selecting the larger figure, but the accuracy is far above chance. The lowest score was 73; a perfect score would be 90. The variation from one series to another was found to be

Table 6

NUMBER OF CORRECT RESPONSES FOR CIRCLE-SQUARE, CIRCLE-RECTANGLE, AND SQUARE-RECTANGLE SERIES

Subjects	Number of Correct Responses* Series C-S	C-R	S-R	Average	Per cent of Correct Responses
AR	75	82	73	76.7	85.2
TP	81	78	75	78.0	86.7
LD	86	76	83	81.7	90.7
CC	88	79	84	83.7	93.0
BB	78	74	84	78.7	87.4
FM	84	80	86	83.3	92.6
MM	82	79	86	82.3	91.5
MW	86	86	82	84.7	94.1
MH	83	84	83	83.3	92.6
AD	84	77	83	81.3	90.4
Average	82.7	79.5	81.9		

*90 trials in each series.
Order of presentation of series is disregarded in this table.

greater than the variation between subjects but here also the variation in both cases can most appropriately be attributed to chance fluctuations. Within the framework of the complex series the ability to discriminate was not seriously affected by the shape of the stimuli since the subjects discriminated between a circle and a square, differing in area, just as readily as they did between a square and a rectangle, also differing in area. There is a tendency for the series with rectangles to have lower average scores, but the difference between the means of the circle-square and circle-rectangle series was found to be unreliable ($P > .05$).

In an attempt to evaluate the efficiency of discrimination in the simple and complex series, the percentages presented in Tables 5 and 6 were compared by means of the variance analysis technique. It was found that the variation among subjects was small enough to be considered a chance fluctuation, but the difference between the scores on the two types of series (simple and compound) was found to be significant at the one per cent level. The results point to more accurate discrimination when the stimuli paired are of the same geometrical shape and statistically this can be considered a significant improvement. The general conclusion is that the child can select the larger of two squares, just as readily as he can the larger of two circles, but selecting the larger of a square and a circle is a more difficult task and more errors are made in the latter discrimination.

The series were presented in a random order to the subjects so that the practice effect would be distributed among the various series. The presence of such an effect can be studied by comparing the scores for the series presented first with those for the series presented second. In this comparison the shape of the figures is naturally disregarded. Table 7 gives the scores for the simple series and Table 8 for the compound series. The differences between the means were found to be unreliable, except in one case: first vs. second simple series ($P < 0.05$). This seems to indicate that during the first series certain adjustments

Table 7

NUMBER OF CORRECT RESPONSES FOR SIMPLE SERIES PRESENTED FIRST, SECOND, AND THIRD -- SHAPE OF FIGURES DISREGARDED

Subjects	Number of Correct Responses Series Presented First	Second	Third	Average
AR	42	44	41	42.3
TP	43	44	43	43.3
LD	40	45	45	43.3
CC	41	45	45	43.7
BB	44	43	42	43.0
FM	45	44	44	44.3
MM	45	45	44	44.7
MW	40	45	45	43.3
MH	43	44	43	43.3
AD	45	44	45	44.7
Average	42.8	44.3	43.7	

Table 8

NUMBER OF CORRECT RESPONSES FOR COMPLEX SERIES PRESENTED FIRST, SECOND, AND THIRD -- SHAPE OF FIGURES DISREGARDED

Subjects	Number of Correct Responses Series Presented First	Second	Third	Average
AR	82	75	73	76.7
TP	75	81	78	78.0
LD	76	86	83	81.7
CC	88	79	84	83.7
BB	78	74	84	78.7
FM	80	86	84	83.3
MM	86	82	79	82.3
MW	86	82	86	84.7
MH	83	83	84	83.3
AD	77	83	84	81.3
Average	81.1	81.1	81.9	

were made by the subjects which enabled them to improve their scores in the succeeding series. Practically all the practice effect occurred within the first series.

SUMMARY AND CONCLUSION

The ability of young children (4 to 7 years of age) to discriminate between stimuli varying in size was studied by the standard discrimination technique. The stimuli were circles, squares, and rectangles. In one part of the experiment the paired stimuli were of the same geometrical shape (e.g., large square vs. small square), whereas in another part the stimuli differed in shape (e.g., large square vs. small circle).

Ten of the 12 subjects used in the experiment learned the initial discrimination. The number of trials taken to learn this discrimination varied from 5 to 437 trials. It is believed that the variation is due

to individual differences rather than to the shape of the stimuli.

The results of the simple series (stimuli of the same shape) make it possible to conclude that the subjects are able to select the larger of two circles, squares or rectangles with about the same amount of accuracy.

From the results of the compound series (stimuli of different shapes) it can be concluded the subjects were able to discriminate the larger stimulus from the smaller even though the shapes of the two figures were not the same. The accuracy of discrimination was approximately the same regardless of whether the stimuli were circles and rectangles, or squares and rectangles.

When the simple and compound series were compared, it was found that the task of selecting the larger of two figures differing in shape was more difficult than selecting the larger of two figures of the same shape. That is, the child is able to select the larger of two squares, just as readily as the larger of two circles; but selecting the larger of a square and a circle is a more difficult task as evidenced by the fact that more errors were made in this type of discrimination.

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THE PEDIATRIC ANAMNESIS
INACCURACIES IN ELICITING DEVELOPMENTAL DATA[1]

MYRTLE B. McGRAW AND LOUISE B. MOLLOY

It is a matter of common knowledge that the part of a pediatric anamnesis which pertains to the past health and development of a child is often reported inaccurately by the mother. Yet on occasions an accurate knowledge of these happenings is important diagnostically. Too often in our hospitals and clinics the taking of the history is conducted in a fairly routine manner by a person who may have no subsequent contact with the patient.

The present study was undertaken to determine the extent to which specific questioning, particularly with reference to developmental features, would evoke greater accuracy of report. Except for rare instances when a mother tries to cloak certain facts, inaccuracies in her report can be attributed to two main factors: 1) failure in memory, and 2) the asking of such vague questions that they do not have the same meaning to the questioner and to the respondent. Failure in memory may result from failure to observe in the first place. It may represent an unconscious effort to suppress a disagreeable experience or, if no significance was attached to the phenomenon under inquiry, it may represent a simple lapse of memory.

The only previous systematic study of the accuracy of mothers' reports was made by Pyles, Stolz, and Macfarlane (1). They examined the reports of 252 mothers who had cooperated in the Berkeley Survey. During the first year of life a certain body of data concerning the birth and development of the child was obtained by a nurse during quarterly interviews with the mothers. Since the memories of the mothers were not taxed beyond a 3 month interval, it was assumed that the original reports were accurate. When the children were 21 months old, a subsequent record was obtained from the mother by the examining physician. These later reports were compared with the earlier ones. Among the items included in this study were: 1) age when the child walked alone, 2) age when the first tooth appeared, 3) weight at 1 year, and 4) diseases during the first year. Some of the conclusions will be discussed later in this paper.

The women interviewed in the present investigation were mothers of 42 children who have been subjects of a longitudinal study by the Normal Child Development Study during the past few years. Detailed recordings of each child's behavior development constituted one of the major undertakings of the project. These ratings provided the reference base against which mothers' reports could be checked. The Study also compiled fairly complete health records of each child. Health records were based upon physical examinations performed by a pediatrician at the time of each visit to the laboratory and were supplemented by home visits of the visiting nurse. Except for omissions these records can be considered to be highly accurate.

The socio-economic level of the mothers was on the average lower than that in the Berkeley Study. The formal educational background of

[1] *From the Normal Child Development Study of the Department of Pediatrics, Columbia University, and the Babies Hospital.*

CHILD DEVELOPMENT, Vol. 12, No. 3 (September, 1941)

the mothers was predominantly grade school though about 10 had gone through high school. Both because of educational background and because the mothers in the Berkeley group were questioned at intervals of 3 months, it is probable that their observations were more accurate than those of the mothers in our group.

The ages of the children at the time the mothers were interviewed varied from 2½ to 8½ years. So the time intervals in this investigation were greater that those in the Berkeley Study. The procedure followed was to hold two interviews with each mother several months apart. The first interview called for information concerning the child's health and development in essentially the same manner as it might be asked for at the time of admission to the out-patient department of the hospital. Questions on the following items were asked in the following manner:

FIRST INTERVIEW

1. When did the baby begin to hold the head up?
2. When did he begin to sit alone?
3. When did he begin to creep?
4. When did he start to walk alone?
5. When did he begin to roll over?
6. When did he begin to pull up on furniture to a standing position?
7. When did he start drinking from a cup?
8. When did he stand alone?
9. When did he begin to get into a standing position alone?
10. When did he cut his first teeth?
11. When did he begin to reach for objects?
12. When and what illnesses has he had?
13. When did he start to talk?
14. Had he been vaccinated or immunized against any of the contagious diseases? If so, when?

The answers of the mothers, made during the interview, were checked against the records of the Study. The behavior data collected by the Study consisted of ratings on sequential phases in the development of selected activities (2, 3, 4, 5). Therefore in comparing the mothers' reports with our data it was necessary to decide arbitrarily which phase we should select as the standard against which to compare the mothers' reports. If the mothers' reports agreed within a month of the date recorded in our records the answers were accepted as correct.

It would seem reasonable to expect a mother's report of illnesses, operations, and physical signs of development to be relatively more accurate than her recollection of behavior development. Actually our records revealed at least 50 instances of severe or moderate illnesses and surgical operations which were not recalled by the mothers at all. This figure represents 35 per cent of the total numbers of illnesses recorded in our records. Some of the forgotten items were: Bronchopneumonia, acute otitis media, myringotomy, measles, mumps, chickenpox, scarlet fever, tonsillectomy, bronchitis, mastoiditis, mastoidectomy, hemolytic streptococcus, pharyngitis, fractured skull, acute laryngotracheitis, cellutis of the face, and an infected sebaceous cyst. Even

when the mothers recalled a specific illness, they frequently did not remember exactly the time of its occurrence. When the physical and health items which were recalled were combined it was found that 33 per cent recalled the time correctly within 1 month; that the time as reported deviated from our records by more than a month in 30 per cent; and that 37 per cent could not remember when the events took place. On the average the mother miscalculated the age of occurrence of such events as cutting the first tooth, measles, chickenpox, whooping cough, scarlet fever, pneumonia, bronchitis, tonsilitis, vaccination, diphtheria immunization and Schick test, by 3 months. Those reporting on chickenpox and whooping cough deviated on the average from the actual date by 8 and 5 months respectively. The mothers miscalculated the time of eruption of the first tooth by 2½ months, and on both physical development and diseases there was a definite tendency to state the time earlier than the actual occurrence. These findings substantiate those of Pyles, Stolz, and Macfarlane who reported that only 36 per cent of the mothers in their study recalled the eruption of the first tooth accurately. The average discrepancy is larger in our group than was found by the Berkeley Study. Pyles and associates also reported that the mothers tended to forget slight illnesses during infancy. Our findings show that the mothers tended to forget the severe illnesses as much if not more than the less severe ones. It is possible that this failure represents a human tendency to suppress disagreeable experiences. The report of disease incidence might have been quite different if the history had been taken when the child was actually being admitted to a hospital because of some ailment. That is, when a child is ill the mother may be reminded more of previous ailments than if questioned when the child is well. It also has been suggested that the mothers of the socio-economic level studied accept common contagious diseases as an inherent part of childhood and that such illnesses are not registered deeply in their minds.

With regard to the questions on the development of behavior: 23 per cent of the answers agreed with our records within a range of 1 month; 46 per cent deviated from our records by more than a month; in 31 per cent the time of occurrence was not recalled. Of the 46 per cent which did not agree with our records, in 39 per cent the date of occurrence was given earlier than it actually happened and in only 7 per cent at a later date. The greatest discrepancies occurred in reporting the age of standing alone, walking alone, sitting alone, rolling over, and creeping. In magnitude of discrepancy the age of "walking alone" showed the greatest deviation. On the average the deviation from our record in this item was 3.6 months, and the tendency (algebraic average of the deviations) was for the mothers to report the time 3.2 months earlier than its actual occurrence. In reporting the age of sitting alone the mothers deviated from our records by 2.6 months, and the tendency was to report the achievement 2.5 months earlier than its actual occurrence. In reporting the age at which the babies rolled over the mothers deviated from our records by 2.4 months and on the average they reported a date 2.1 months earlier than it actually occurred. Fifteen per cent of the mothers reported that their babies never crept, although we have movie records on each child to the contrary. Those who reported on the age of creeping deviated from our records by 1.9 months and their estimates were 1.6

months earlier than our records. There were only two items on which the dates reported by the mothers were later than those established by the record. These were: 1) holding the head up, and 2) reaching for an object; the underestimations were, on the average, of a magnitude of 0.3 and 0.2 of a month, respectively.

These findings clearly indicate that when mothers are asked general questions concerning the child's behavior development during infancy they tend to report an earlier date than that corresponding to the actual achievements.

SECOND INTERVIEW

In the second interview, which took place several months after the first, several questions were asked about each behavior item. The purpose was to determine whether more specific questioning would bring out greater accuracy in the mothers' reports. These questions will be presented under the heading of each behavior item.

Rolling Over

Instead of being asked merely when the child rolled over - which may mean from back to stomach or from stomach to back - the mother was shown the accompanying drawing (Fig. 1) and asked:

Fig. 1. Drawing accompanying question 1 on Rolling Over.

1. Do you recall when your baby would throw the head back and arch the spine as he pushed with one foot against the bed as if trying to roll from his back to the stomach?
2. Do you remember when he began to roll from back to stomach without much difficulty?
3. Do you recall when you found it difficult to change the diaper because as soon as you placed him on his back he would immediately try to turn over on the stomach?

When questioned in this manner 42 per cent gave correct responses as against 15 per cent in the first interview. Moreover, the magnitude of deviation was noticeably reduced. In answer to the first question they

deviated from our records on the average only by 0.9 of a month and they reported the age earlier than it actually occurred by only 0.5 of a month. The answers to the last two questions disclosed an average inaccuracy of 1.8 of a month with a directional deviation toward a younger age of 0.9 of a month; the corresponding values in the first interview were 2.4 months and 2.1 months, respectively.

Sitting

The questions asked with respect to this activity were as follows: (Line drawings were also shown the mother.) (Figs. 2 and 3)

Fig. 2. Drawing accompanying question 1 on Sitting.

Fig. 3. Drawing accompanying question 2 on Sitting.

1. Do you remember about the time your baby could sit alone leaning forward on his hands?
2. When could he sit with his back quite straight so that he could handle toys or objects, that is, when was it that he did not need his hands to support himself?
3. Did you notice when, if he was lying on his back, he was first able to get into a sitting position alone, without pulling on the crib bars or being helped?
4. Did he do this by first rolling over on the stomach?

In answer to the first question, the mothers' reports deviated on the average from our records by only 0.7 of a month. Their bias in favor of an early age was only 0.2 of a month. In response to the second question, they deviated from our records by 1.8 of a month, as compared with 2.6 of a month in the first interview, and their bias in favor of an earlier age than that determined by us was only 0.5 of a month. Their answers to the third question deviated from ours by 2.5 months, but they showed more caution in setting the date of achievement since on the average they underestimated the actual achievements by 0.1 month, i.e., to this extent they estimated a later date than the one shown in our records. It appears that when questions are asked about stages of development which are not commonly called to the attention of mothers they are more cautious in reporting the age of achievement.

Creeping

The mothers were shown line drawings and asked the following questions

concerning creeping: (Figs. 4, 5, 6).

Fig. 4. Drawing accompanying question 1 on Creeping.

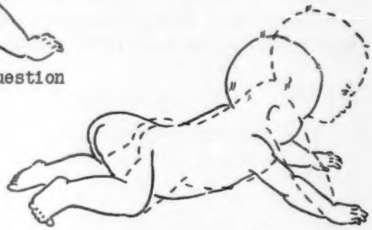

Fig. 5. Drawing accompanying question 2 on Creeping.

Fig. 6. Drawing accompanying question 4 on creeping.

1. Do you recall at about what time your baby, when placed on the stomach, would tend to keep his hips down flat, but would raise his chest and push up on his arms something as in this picture?
2. When did he first begin to raise his stomach up off the floor and perhaps rock back and forth as he supported himself on hands and knees, though he couldn't actually creep about?
3. When was he able to go creeping all around the floor rapidly?
4. Did he do this with his stomach still on the floor, or did he go on hands and knees, on all fours, that is on hands and feet, or did he push himself about in a half sitting position?

Questions 1 and 2 refer to stages of development about which mothers are not commonly questioned, and in their answers to both they tended to

underestimate slightly the achievements of the babies. In answer to question 1 they deviated from our records by 1.4 of a month, and underestimated the achievement by 0.5 of a month. The answers to question 2 deviated from our records on the average by 1.4 of a month, but the underestimation was only 0.06 of a month. In any event they did not overestimate, or tend to set a date earlier than the actual occurrence. On question 3, which would correspond more closely to the creeping question of the first interview, their reports deviated from our records by 1.3 of a month, as against 1.9 of a month in the earlier interview, and the average bias in favor of early achievement was 1.1 month as opposed to 1.6 months in the previous interview.

Walking

Line drawings were shown and the following questions were asked concerning walking: (Figures 7, 8, 9).

Fig. 7. Drawing accompanying question 1 on Walking.

Fig. 8. Drawing accompanying question 4 on Walking.

Fig. 9. Drawing accompanying question 5 on Walking.

1. Do you recall when, if you held your child up so his feet could touch the floor or bed, he would tend to stand on his toes with the shoulders forward, something as in this drawing?
2. Do you remember when he could walk easily if you led him by the hand, though he could not walk alone?
3. Do you remember when he began to take several steps without holding on to anything?

4. Do you remember at about what age he walked with the arms away from the body and with his feet wide apart - something as in this drawing?
5. At about what time do you think he began to walk with the arms down by his side, or perhaps swinging, and the feet not so far apart?

The mothers apparently did a fair amount of guessing in answer to question 1. On the average they deviated from our records by 4.5 months, but some obviously underestimated the child's achievement and others overestimated it, since as a group they underestimated these dates by only 0.9 of a month. Their answers to question 2 deviated from our records by 1.4 months, and again they underestimated the actual dates by 0.9 month. The answers to questions 3 and 4 were combined since according to our rating system they represent the same stage of development. The mothers' reports deviated from our records by 1.5 months, and they overestimated the achievement, that is, reported an earlier date than was actually obtained, by 0.4 of a month. Their answers to question 5 deviated by 3.7 months, which is essentially the same as the deviation reported for walking during the first interview. Also they overestimated the achievement of the babies by 3.5 months as compared with 3.2 months during the first interview. These appraisals seem to suggest that in the eyes of the mother the baby walks in a comparatively mature manner from the very beginning; or at least they intimate that she is not observant of the details which indicate change after the onset of independent walking.

Holding the Head Up

It is doubtful if even the clinicians know just what they mean when they ask, "When did the baby hold his head up?" Do they refer to the time when the baby merely holds the head steadily on the shoulders so that the head does not drop forward as the baby is carried about in the arms of an adult? In any event it was thought that more specific answers might be elicited if we asked when the child could hold the head in a lifted position while he was lying in a prone position. In connection with showing the line drawing of Fig. 10 the following question was asked:

"Do you recall when the baby began to hold his head up when he was lying on his stomach and appeared to look around? That is, when did he actually hold the head lifted so that it was not merely bobbing up for a second or so?"

Fig. 10. Drawing accompanying the question concerning Head Control.

Since we had not recorded in our developmental series any information on "holding the head up" as such, the answers of the mothers in the first and the second interviews were checked against the child's ratings of this phase of prone behavior. To our surprise, 47 per cent gave correct responses on the first interview as against 26 per cent in the second interview. For some reason the general question as asked in the first interview evoked responses which agreed with our records better than the question presented in the second interview. We have already seen that the mothers tended to be cautious when confronted with less familiar questions, and in this instance they were apparently overly cautious, especially since in the second interview they underestimated the date by 1.7 months.

Reaching

In an effort to determine when the child was engaging in more purposeful reaching-prehensile behavior, the mothers were asked:

"At about what time did the baby begin to reach out for an object, and if it was beyond his arm's length, he would lean forward in order to reach it?"

Stated in this manner the improvement in the correctness of response was not appreciably increased. The mothers' reports in the first interview deviated from our records by 2.2 months and in the second by 2.1 months. However, they did show less of a tendency to overestimate the child's achievement. On both occasions they showed a tendency to state the age of achievement as later than the actual occurrence; in the first interview they underestimated the date by only 0.2 of a month, and in the second by 2.2 months.

When all the behavior items are considered, the percentage of incorrect responses as obtained in the first interview was just double the percentage of correct responses; whereas, in the second interview the percentages of correct and incorrect responses were equal. Furthermore the mothers manifested a much greater tendency to overestimate the achievements of the babies during the first than during the second interview. In the first interview 39 per cent of the responses reported more precocious behavior than that shown in the Study records and only 7 per cent as less so. In contrast to this 13 per cent during the second interview reported younger ages than the actual occurrence as against 18 per cent who reported ages later than those recorded by the Study.

The research records did not provide any accurate data on the development of speech. However, it was thought worth while to try to ascertain just what mothers have in mind when they say their children begin to talk. In the first interview the mothers were asked simply when speech developed. In the second they were asked the following questions:

1. Do you recall the period when the child would look at you and chatter in such a manner that it sounded as if he were really speaking but in a foreign language or in a language of his own, though you could not recognize actual words?
2. At about what time did he begin to point to things and utter sounds which you or others familiar with him recognized as his word for the ob-

ject because he would make the same sound again and again in connection with that particular object?
3. When did he develop to the stage when other people who were not with him practically every day could understand his speech as well as you?

Only 30 mothers reported on these questions. In 12 instances the age given to question 1 agreed with the one they had reported for the development of speech in the first interview; another 12 apparently considered the conditions stated in question 2 as evidence of the development of speech, and 6 reported the same age for the development of speech as that given for the answer to question 3.

It seems apparent from these data that more specific questions do elicit more accurate reports on the part of mothers; and even more outstandingly, the detailed questions suppress a tendency to overestimate the baby's achievements.

No attempt was made in the second interview to extract more accurate information on the health and physical development of the child, but undoubtedly questions could be formulated which would elicit more complete and accurate reports than those obtained.

SUMMARY AND CONCLUSIONS

The purpose of the present study was not only to appraise the accuracy of mothers' reports concerning the development and health of their children but also to determine whether more specific questioning would evoke more accurate reportings. Mothers of 42 children were given 2 interviews. Questions during the first interview were presented in the general manner in which they are commonly asked in taking clinical histories. In the second interview several more detailed questions were asked concerning each behavior item. The reports from both interviews were checked against the records compiled by the Normal Child Development Study for research purposes.

The findings from these interviews indicate that mothers often fail to recall the occurrence as well as the time of moderately severe illnesses. In reporting both physical and behavior development there was a definite tendency for the mothers to overestimate the achievements of the child, i.e., to state an age younger than that of the actual achievements. More specific questioning not only improved the accuracy of reporting but even more strikingly decreased the tendency to overestimate the child's accomplishments. Indeed when asked to recall a less commonly observed phase of development the mother often underestimated the achievement of the child. From these findings it seems apparent that improved questioning can add considerably to the accuracy of clinical histories.

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QUANTITATIVE STUDIES IN THE DEVELOPMENT OF ERECT LOCOMOTION[1]

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The advantages derived from converting experimental datum into numerical form are self-evident. The problem of reducing behavior to mensurable terms is difficult, but the difficulties met in quantitating the development of behavior are even more troublesome. There are no common units, such as pounds or inches, for the representation of behavior, but whatever yardstick may be adopted, during development it is constantly changing, changing in form and changing in magnitude. It is this fact of continuous change which augments the difficulty of finding satisfactory units for mensuration. Anyone who has observed a child learning to walk knows that innumerable qualitative changes take place before an individualistic gait becomes established. The toddler holds the arms in extension and abduction; the lower extremities are somewhat flexed at the knees and hips; the base is wide; and he tends to pick each foot up and put it down as if it were a club. Later he steps in heel-toe progression and swings his arm synchronously with movements of the opposite leg. Such changes in manner of walking indicate development but these changes are difficult to express in symbolic form.

The purpose of the present study was to determine whether or not serial observations on a form of behavior which exhibits sequential developmental features could be reduced to symbolic and preferably mathematical expressions not of the sequential features themselves but rather of the dynamic element of change which leads one form of behavior to give way to the next. Erect locomotion was selected as the exemplary behavior activity because already a considerable body of data had accumulated on both the development and the mechanics of walking, and because the literature on the mechanics of bipedal walking provided some suggestive techniques for the measurement of development. Although the results obtained do not yield the desired unit - inch, pound, erg, or ohm - for measuring neuromuscular development, the technique applied will be of interest to students of child development and to investigators in allied fields. It is recognized that the adoption of any method of investigation is determined both by the objective and by available facilities for recording and analyzing data. Numerical values for a growing phenomenon are not sought as an end in themselves but rather as a means of formulating more adequate expressions of general principles. This investigation was undertaken with the hope that some of the observed qualities of growth such as periods of oscillation and distinctions between incoordinate and integrated movements could be more objectively demonstrated. That the objective was only partially realized will become apparent in the course of discussion.

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LITERATURE

Pertinent literature on the subject falls roughly into two classes: (a) those studies which demonstrate means of obtaining objective measures of the mechanics of erect locomotion and their interpretation into known physical principles, and (b) those studies which have concerned the de- development of erect locomotion in the growing infant.

A. On the Mechanics of Gait

Aspects of the mechanics of walking which have been the subject of investigation may conveniently be classified into the following divisions:

1. Spatial relationships of the feet on the ground.
2. The time sequence of placing the feet on the ground.
3. The force exerted by the foot on the ground.
4. The path of various parts of the body through space during a given interval of time.
5. The velocity, acceleration, and resultant force for the parts; the total mechanical work done, and mechanical efficiency.
6. Muscle action.

Footprint techniques have been used by several investigators to determine such factors as angles of inversion or eversion, base width and length of step. Also footprints have yielded approximate determinations concerning the anatomical structure of the foot and the particular part of the foot which bears the greatest weight during locomotion. As early as 1881 Vierordt (32) mounted styluses at selected points on the shoes; Dougan (5) had persons wearing hob-nail shoes walk on carbon paper; and Burnside (3) obtained barefoot prints of subjects walking on an ink pad covered with brown paper. Wolff, (35) more interested in pressure points, had barefoot subjects step in French chalk before walking on black photographic paper. Kreezer and Glanville (17) used another method than footprints for obtaining measures of base width and eversion of the toes. They took motion picture records of persons approaching and walking away from the camera and then measured the transverse distance from the centers of the heels.

In the latter half of the nineteenth century investigators became concerned with measurements of the time sequence involved in stepping, that is, the time that the sole or a part of the sole was in contact with the surface. These factors were studied by Carlet (4), Marey (19), Schwartz (25, 26), and Hubbard and Stetson (15). The method commonly employed, particularly by the earlier investigators, consisted of shoes constructed with two or three air chambers. These air chambers were connected to recording instruments, usually kymographs, by rubber tubes. From the kymograph records it was possible to ascertain the time each foot was on the ground, how long both feet were simultaneously on the ground, and the length of time consumed in completing a step. To keep the subjects walking a constant distance from the recording system some of the investigators used a circular track while others used a treadmill. Schwartz (27, 28) placed electrodes as well as air chambers on the shoes at the level of the heel, the lateral metatarsal arch, and the great toe. When the electrodes came in contact with the aluminum surface of a tread-

mill, lamps were lighted. The lighting of the lamps was recorded on motion picture film which yielded a measure of the time during which a foot was in contact with the underlying surface.

Several methods have been used in studying the distribution of weight during locomotion by determining the points of greatest pressure. Early investigators placed a thin lead plate over a distribution of steel shot. When the subject stepped on the plate the deeper indenture of the shot into the under-surface of the lead plate indicated the points of greatest pressure. A wire mesh placed over an ink pad and covered with paper on which the subject walked was also used as an indicator of pressure distribution. Morton (24) used a rubber mat with longitudinal ridges. The rubber mat was covered with an inked ribbon and paper. The longitudinal ridges of the mat broadened under pressure so that the prints of the widest ridges reflected the areas of greatest pressure during walking. Elftman (6) modified the rubber mat technique so that not only the area but the points of greatest pressure during locomotion could be accurately determined in terms of spatio-temporal relations. He used a rubber mat the under-surface of which was covered with pyramidal projections. The mat rested on a heavy glass plate which was covered with white liquid. The under-surface of the glass showed black dots against a white background. When pressure was placed upon the mat the area of the black pyramidal points increased. A movie camera placed beneath the glass plate photographed the footprints as the subject stepped on the mat. Such movie records provided not only evidence of the area of greatest pressure but also indicated where the pressure was greatest at a given moment. Previously Fenn (11) had used a different method for obtaining measurements of the force exerted by the foot upon the substratum during sprinting. The apparatus consisted of a platform mounted on a set of compression springs in such a way that the vertical and horizontal forces could be indicated by deflections in the springs. Elftman (7) employed a similar apparatus for measuring the magnitude, direction, and point of application of the force exerted by the foot upon the substratum during each instant of walking.

The position and movements of various parts of the body during erect progression have been exposed to considerable analysis during the past hundred years. As early as 1836 Weber and Weber (33) became interested in the inclination of the body during walking as well as in the length and duration of steps. Carlet (4) by attaching rods to the clothing of the subject was able to record movements of different body parts mechanically. In the pre-cinema days both Marey (19) and Braune and Fischer (1) were applying a chronophotographic technique to measurements of changes in trunk and leg movements during walking. Marey (19) had his subjects wear tights which had lines drawn along the lateral aspect of the trunk and the legs. As they walked he made exposures at regular intervals on the same photographic plate. Braune and Fischer (1) placed Geisler tubes on their subjects and used a similar photographic technique for recording changes in bodily members. More recent investigators have utilized motion pictures as a means of determining changes in bodily parts during progression. Kraus (16) traced successive positions of the legs as exposed in sequential movie frames, after superimposing the torso of each frame. The same method was employed in tracing the path of arm and

shoulder movements during a step. Glanville and Kreezer (14) have made use of the cinematographic technique in studying abnormalities of gait as well as characteristic features of adult locomotion. From studies of ten normal adults they published norms on some of the more critical features of orthograde progression. Elftman (8) likewise has used the frame by frame analysis to determine the time and space displacement of body and extremities during walking.

The treatment and interpretations of data obtained on posture and movements during progression are variable. Usually the motion of the flexion foci (hips, knees, and ankle) and centers of gravity (for example, of body, thigh, and leg) have received particular attention. Kraus (16) attempted to identify particular movements with special muscle groups. Hubbard and Stetson (15) determined the correspondence between muscular movements and action potentials during walking. Some of the investigators have gone into elaborate analysis of the forces and counterforces involved in orthograde progression. Once the path of the body and its parts through space have been determined on a time basis the velocity and acceleration of movements of various parts of the body can be calculated. When the acceleration and velocity are known the resultant forces and torques together with the power exerted to move the mass in question can be ascertained. Finally, with these data, the overall efficiency of the body in walking can be determined if the metabolism is also known. Calculations of work done, or power output, were made by Marey (19), Fenn (10, 11), and Elftman (9). Probably one of the most thorough studies and discussions of the various mechanical and physical factors involved in orthograde progression is that presented by Steindler (31). He accepts the general laws of mechanics as a standard against which the validity of human motion can be measured. "Everything", he says, "depends upon proof that the body in a particular motor event is subject to the general laws of mechanics and that in its makeup and functions it shows a response to the demands and precepts of these laws." (p. 10) He then proceeds to show that the human body, like all terrestrial bodies, is subject to the law of gravity, and he expresses locomotion in terms of Newtonian laws of motion, forces, stresses, inertia, mass, rotatory, and translatory motion.

While many of the physical aspects of locomotion have been analyzed with meticulous care, the task of measuring quantitatively developmental qualities in the achievement of locomotion is far from realization. Long before cinema techniques were available, Professor Mach, viewing the methods of Marey (19), suggested that a number of photographs of the same individual be taken at equal intervals of time, from the earliest infancy to extreme old age. Then the successive series of images could be arranged and viewed in Plateau's phenakistoscope. "If this were done, a series of changes, which had been brought about during a period of many years, would pass before the eyes of the beholder in the course of a few seconds, and thus the stages of a man's existence would pass in review before the gaze of the onlookers in the form of a strange and marvellous metamorphosis." (p. 312)

B. Studies of Development of Orthograde Locomotion

Investigation of the development of erect locomotion obviously in-

troduces greater complexities. In dealing with the mechanics of locomotion time is considered as a fourth dimension, that is, three dimensional space plus a measurement of the time as a factor in each particular step. A study of development in locomotion introduces another time axis, namely that which extends across the period of individual growth. It is not surprising that investigators of development in this function have not been able to adopt the complicated methods applied in a study of the mechanics involved in walking.

Indeed, many students of functional development in this respect have been content merely to determine the age range for the appearance of the first independent step, or a temporal listing of the various activities which obviously contribute to the acquisition of erect locomotion. In 1920 Gesell (12) published age norms for such items as "walking with help" and "walking independently". Linfert and Hierholzer (18) as well as Bühler and Hetzer (2) determined the average age at which an infant should roll from a supine to a prone position, sit alone, creep, stand with and without help, and walk alone. These sequential achievements are recognized as precursors of walking, and most of the normative data on orthograde progression end with independent locomotion. However, as early as 1920 Simon (30) obviously recognized that there was a distinction between the "stepping" of the young infant when supported under the arms from the "step" of the older baby when supported only by the hand. In 1932 McGraw (20) stressed that progressive movements appeared to be organized at a reflex level in the newborn infant and that age norms would not achieve their optimum usefulness until distinctions in the quality of movements were differentiated beyond such standards as "standing and walking with help or alone, et cetera." In 1931 Shirley (29) studied the development of 25 infants during the period of walking and pointed out sequential stages both prior to and following the onset of independent walking. According to her criteria there are 5 prewalking stages, as follows: "(a) an early period of stepping; (b) standing with the support of a person; (c) walking with help, led by a person; (d) standing alone; and (e) walking along." Development after the onset of independent walking was indicated by "(a) gradual increase in walking speed; (b) increase in length of step; (c) decrease in width of step; (d) decrease in angle of step; (e) increasing tendency toward straight rather than out-toeing steps." Later normative data presented by Gesell and Thompson (13) embraced more details such as postural adjustments of the head and leg and foot movements when the infant was in a standing position, though they did not at this time attempt to show the gradual evolution of one stage into another in the ultimate achievement of orthograde progression. In 1940 McGraw (22) emphasized the sequential neuromuscular configurations exhibited in the attainment of erect locomotion. Criteria were formulated for rating seven significant phases occurring between the reflex-stepping of the newborn infant and the achievement of an integrated gait. These criteria were derived from repeated observations upon a group of 82 children over a period of years. The ratings obtained provided a means of determining the age period during which each phase was the most characteristic mode of behavior. It was contended that each phase reflected reorganization in the central nervous system, and that the onset of independent walking was merely a milestone

in the process of development and not the end result.

In view of the many difficulties involved it is understandable that quantitative measures on the development of erect locomotion are sparse. The factors to be considered are multitudinous, and during development each factor is constantly changing, and changes in one aspect may be expected to influence another. However, as early as 1881, Vierordt (32) had applied his technique for measuring the time phase in a step to the study of walking in young children. His device consisted of shoes so constructed that when the heel or toes of the foot were raised above the ground an electric curcuit was interrupted which stopped the recordings on a kymograph. The 2 children studied by Vierordt (32) were 2½ and 4 years old, and by that age the major form changes in the development of erect locomotion have already taken place. However, even at this age children differ from adults in the width of stride and the angle of the foot with respect to the direction of locomotion. When comparing the gait of the child with the adult he found that the duration of each step and the time during which the supporting foot remains on the ground show greater variation in the child than in the adult, and also that the planting of the foot takes a longer time than it does in the adult. The device which Vierordt (32) used for measuring stepping length and the degree of eversion or inversion consisted of a pair of shoes to which were attached hollow cylinders - one at the back of the heel and the other two on the internal and external borders near the metatarso-phalangeal joint. These cylinders contained fluids which left a mark on the paper upon which the subject was walking. This was one of the first devices used for obtaining "footprints" of children during progression. Since then more simple techniques have been used in recording progressive footprints. In 1927 Burnside (3) published a study in which she had used an ink pad technique for making footprints of infants who were just beginning to walk independently. From these records she ascertained variations in the width of step and the length of "double step" on several children though she did not show progressive development in these respects. Shirley (29) also used the ink pad technique for recording footprints, and from these records she presented measurements on developmental changes in length of step, width of step, and degree of angulation both before and after independent walking. Wolff (35) used still another method in making footprint records of children walking. She had the children step in French chalk and then walk on large sheets of black antique Buckeye paper. The chalk footprints were fixed upon the paper by a spraying of shellac and alcohol. Wolff (35) claimed that this method provided not only adequate data for measuring length of stride and width of step, et cetera, but also the points of greatest pressure. During walking the powder was dispersed at the points of greatest pressure and tended to accumulate where the pressure was less.

In addition to the use of ink pad footprints as an instrument of measuring certain aspects of the development of erect locomotion, Burnside (3) published one of the first studies wherein the motion picture film was used not only as an instrument of recording but also as a device for measuring certain time factors involved in the development of walking. She photographed nine different babies at irregular intervals, the observations being started when the babies were between 6

and 8 months of age. The number of repeated recordings on each child varied from 1 to 7. The time consumed in stepping was measured by counting the number of 16 mm. frames exposed during the movement of each foot forward, the exposures being made at 16 frames per second. Repeated measurements of this order were not obtained upon enough children nor upon the same child a sufficient number of times for a developmental trend to be demonstrated. McGraw and Weinbach (23) showed, by counting 16 mm. movie frames recording the gait of 1 child over a period of 3 years, that at the onset of independent walking the time consumed in swinging the left and right legs forward might vary as much as 15/16 of a second during 12 consecutive steps. By the time the gait was well established, when the child was 3 years old, this time difference in the forward movement of the 2 legs was not more than 2/16 of a second. In this same report, it was pointed out that the static equilibrium of the toddler is superior to that of the older child but that the balanced antagonistic action of the extensor and flexor muscles was obviously more efficient in the older child.

From these several studies on the development of erect locomotion in the child, it is apparent that the major changes take place during the first 30 to 36 months of life. After that time individual idiosyncrasies develop but the fundamental features of orthograde progression are established. The most significant features wherein developmental changes are expressed may be summarized as follows:

1. Progressive change in foot contact with the underlying surface.
2. Changes in posture:
    a. Flexion, extension, abduction, and adduction of the upper extremities.
    b. The angle of the vertebral axis with respect to the floor.
    c. The degree of flexion in the lower extremities.
    d. Base width.
3. Variations in the urge for propulsion.
4. Changes in anti-gravity or weight bearing mechanisms.
5. Changes in speed and length of step.
6. Equilibratory control.
7. Changes in the quality of neuro-muscular movements.
    a. Increasing consistency in the successive movements involved as expressed in time-space components.
    b. Progressive elimination of superfluous or excessive movements as optimum efficiency is attained.

Obviously the innumerable technical difficulties explain the dearth of quantitative measurements on the development of orthograde progression, and why so many of the studies of development of erect locomotion in the infant have remained on the descriptive level.

In 1935 McGraw (21), dissatisfied with descriptive data, became interested in measuring quantitatively not only developmental changes in postural configuration, but more subtle changes which reflect degrees of functional integration, increase in synergy, and the shift from staccato to integrative movements in the act of walking. With assistance from all staff members of The Normal Child Development Study and with the aid of methods adopted by others in studying the mechanics of locomotion, a system of recording developmental changes in erect locomotion was finally evolved.

TECHNIQUE OF RECORDING

Elftman (6) had devised a method of measuring with precision the pressure exerted upon the substratum by the foot during each instant of a single ground stroke. This apparatus consisted essentially of a glass plate framed and mounted between two tables. This glass plate was covered with white fluid (evaporated milk), and on it was placed a rubber mat, the upper surface of which was smooth and the lower, studded with pyramidal projections. When a foot was placed on this mat, the surface area of the pyramids increased in proportion to the pressure increase; when the pressure was released, the pyramids contracted and the white fluid filled the space. By means of ultra-rapid cinema photography, instantaneous changes in pressure were recorded as increased or decreased area of rubber in contact with this glass. The camera was placed below the glass so as to photograph the image directly. Elftman photographed the pressure only during one ground stroke, and his determinations were made by measuring the change in area of each pyramidal locus. An illustration of the records obtained by this technique is presented in Fig. 1.

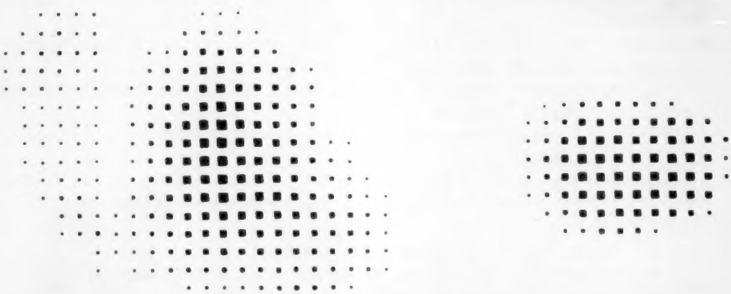


Fig. 1. Footprint obtained by Elftman showing the area of greatest pressure as indicated by increase in pyramidal points.

This technique at first seemed most promising as a method for studying certain developmental changes in locomotion. But as soon as we undertook its adoption we were confronted with unexpected difficulties. In the first place the Elftman mat was large enough to accommodate only one adult size foot, but one can tell an adult just where to step and be confident of his compliance. A baby might walk up and down a table several times and never strike the particular spot under which a foot square glass plate was placed. Since his mat was small, Elftman was able to cut the pyramids in the mat by hand. We preferred to have a long glass plate on which several ground strokes could be photographed. Such images would reveal not merely pressure points but base width, inversion and eversion. We inserted a glass top in a table frame measuring 5 feet long and 26 inches wide. To cut by hand pyramids in a rubber mat of this size was prohibitive. Furthermore, we needed a mat of much softer rubber than that used by Elftman since the light body weight of

newborn infants would scarcely make a dent in gum rubber. We discovered that molding soft rubber into uniform pyramidal projections is difficult since air bubbles may appear at the apex and distort the shape of the pyramid. Finally the late Dr. Dudley Roberts provided us with a mat which worked fairly well though the uniformity of the pyramids was not precise. By that time, however, we had encountered an insurmountable difficulty in the law of optics which caused us to abandon the hope of measuring the exact area of pyramidal points at any instant. Since we desired to have several ground strokes photographed at once it was impossible to obtain the definition of pyramidal points and at the same time record the distance in the position of the two feet. An example of the footprints photographed at a greater distance is presented by Fig. 2 which can be contrasted with the records obtained by Elftman.

Fig. 2. When focal distance is increased pyramidal points are indistinguishable.

Furthermore, our desire to photograph a larger area on each frame necessitated placing the camera at a greater distance from the glass plate. This was achieved by placing a mirror below the glass topped table. This mirror was tilted at an angle of 45 degrees with respect to the glass plate, and the image of the footprints was photographed as reflected in the mirror. A scale, marked off in centimeters, was pasted underneath one longitudinal border of the glass. The image of the scale was reflected in the mirror and photographed along with the footprints. It was thought that this scale would provide a convenient measure of stepping length, but it was actually used for another purpose which will be discussed later.

Since we were interested in determining the time element in walking, by counting the number of frames involved in each step, it seemed im-

portant to have a picture of the child's actual walking in order to know whether a longer ground stroke was a result of incoordination or of some distraction which caused the child to pause momentarily. By moving the camera a satisfactory distance from the table it was possible to photograph the child walking and reflections of the footprints on the same 16 mm. frames. Photographing these two fields simultaneously provoked problems of illumination and focus. In order to provide sufficient illumination for the bottom of the glass plate two 500 watt projector lamps were mounted under each end of the table. The light from these lamps was shielded from the camera by cloth blinds. Four lamps (500 watt) were placed to the side and in front of the table in order to cast light above the table and upon the child. To obtain a picture of the child in a natural gait, additional tables, each 3 feet long were placed at both ends of the glass topped table. A thin rubber covering was placed over the tops of these 3 tables so that there would be no evident lines of demarcation which might cause the child to pause.

The background against which the child was photographed was black. A lateral view of the child was exposed to the camera as he walked the length of the tables. By placing black spots on his body it was possible to follow the course of various parts of the body during progression. The points selected were those corresponding to the level of the center of gravity for the body as a whole, and for the thigh and the leg. The motion of any body may be resolved into two components, the translation of the center of gravity, and the rotation about the center of gravity. For this reason the centers of gravity of the lower leg, the thigh and the body as a whole were chosen as points to follow. These points were determined in the following manner: To facilitate the placing of the marks a table was constructed, Table 1, giving the positions of the centers of gravity from measurements of the distance from the sole of the foot to the center of the patella, for the lower leg; from the center of the patella to the posterior aspect of the buttocks with the lower leg flexed, for the thigh; and the standing height of the individual, for the body as a whole. This table was constructed from the information on centers of gravity of the body and its parts given by Weinbach (34).

An illustration of the photographic frame as it would be seen when projected is presented in Fig. 3.

In making these records a Bell and Howell 16 mm. camera was fastened to a tripod at a distance of 14 or 18 feet from the table edge. The exposure rate was 32 frames per second. This speed of exposure did not appreciably distort the quality of the movement and yet usually allowed definition of each frame even in a lateral view of the subject. A lateral view of a subject walking shows too much blurring when exposed at the rate of 16 frames per second. In ultra rapid exposures distortion of the quality of movement sometimes led to a misinterpretation of the coordination exhibited when the film was projected.

Records were begun on 14 infants during the newborn period and followed until an individualistic gait was well established. During certain periods photographs were made at weekly intervals - these periods being during the newborn phase and at the onset of independent locomotion. At other times the interval varied from bi-weekly to monthly periods. In

TABLE 1

CENTER OF GRAVITY TABLE (FOR LOCOMOTION STUDY)

Leg Center of Gravity - Measure from sole of foot to center of patella.
Thigh " " " - Measure from center of patella to posterior aspect of buttocks with leg flexed.
Body " " " - Measure standing height.

Measure	Leg C of G	Body	Thigh C of G
4	2		2 3/8
5	2 1/2		2 7/8
6	3		3 1/2
7	3 1/2		4 1/8
8	4		4 5/8
9	4 1/2		5 1/4
10	5		5 7/8
11	5 1/2		6 3/8
12	6		7
13	6 1/2		7 5/8
14	7		8 1/8
15	7 1/2		8 3/4
16		9 3/8	
17		10	
18		10 1/2	
19		11 1/8	
20		11 3/4	
21		12 1/4	
22		12 7/8	
23		13 1/2	
24		14	
25		14 5/8	
26		15 1/4	
27		15 3/4	
28		16 3/8	
29		17	
30		17 1/2	
31		18 1/8	
32		18 3/4	
33		19 1/4	
34		19 7/8	
35		20 1/2	
36		21	
37		21 5/8	
38		22 1/4	
39		22 3/4	
40		23 3/8	
41		24	
42		24 1/2	
43		25 1/8	
44		25 3/4	
45		26 1/4	
46		26 7/8	
47		27 1/2	
48		28 1/8	

addition to the infants on whom pictures were made from the time of birth, similar records were begun upon 7 infants prior to the onset of independent walking, (that is, the initial picture was taken sometime between the reflex stepping phase and the onset of walking), and on 29 babies after the onset of independent walking. All told, 1592 photo-

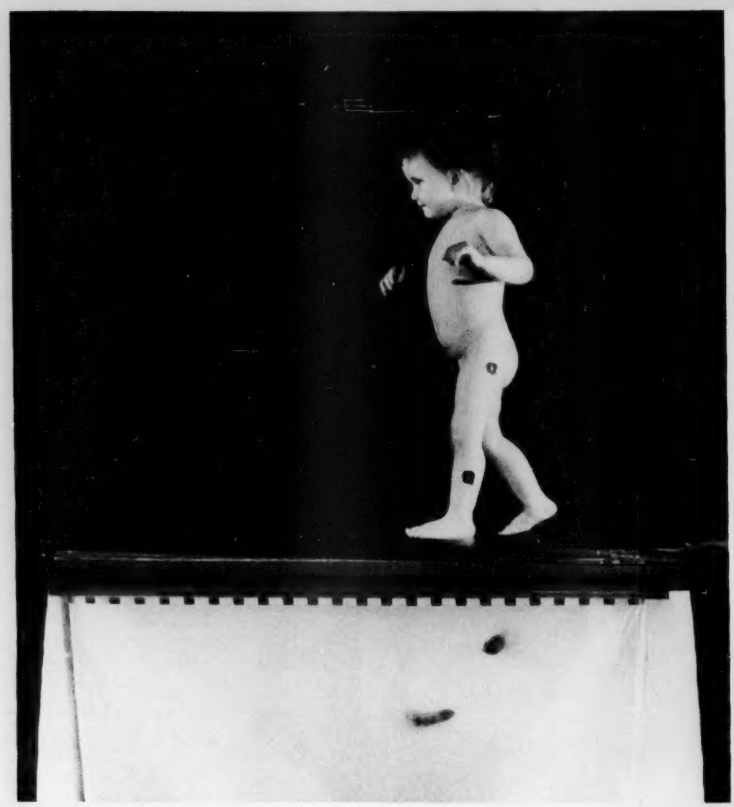


Fig. 3. Picture of child and footprints exposed on the same frame as seen when projected.

graphic records were obtained on 52 children. A total of 15,939 feet of film was exposed in making these records.

Infants who could not walk independently were supported under the arms or held by the hand by an adult. At each recording they were photographed walking in two directions so that both the right and left sides of the child would be exposed. In some instances, particularly with the older children, it was necessary to have them walk the length of the table several times in order to procure a natural gait. Also it was often desirable to distract the child's attention so as to elicit a less self-conscious or less exhibitionary walk.

Data Obtained from Cinema Recordings

After these 15,939 feet of film were exposed the problem of obtaining

the data from the films was colossal. Two types of records were to be translated: (a) those which concerned the path of the body through space, and (b) those which dealt with the time factor as evidenced by the footprints. The methods adopted in transferring these records from film to paper were as follows:

(1) Space-Time factors during progression as revealed by changes in body position. The film was projected on centimeter graph paper. By matching the centimeter scale reflected in the mirror it was possible to reduce all images to comparable dimensions. That is, when 45 cm. on the scale was made to cover 15 cm. on the graph paper a reduction of 1/3 the actual size was obtained. After the adjustments for size reduction had been properly set, the film was projected frame by frame upon the graph paper. With each projection a dot was placed on the paper corresponding to the loci of the three spots marked on the baby's body representing the centers of gravity of the body, the thigh, and the leg. In this manner a graph was obtained showing the path of the body and the segments of the lower extremities. Such a graph is shown in Fig. 4. The vertical lines connect the dots which correspond to the spots on the baby on any particular frame projection. It is possible, therefore, to determine the relative position of bodily members and the distance moved during any fraction of a second. A photograph illustrating the manner in which these curves were obtained is presented in Fig. 5. It should

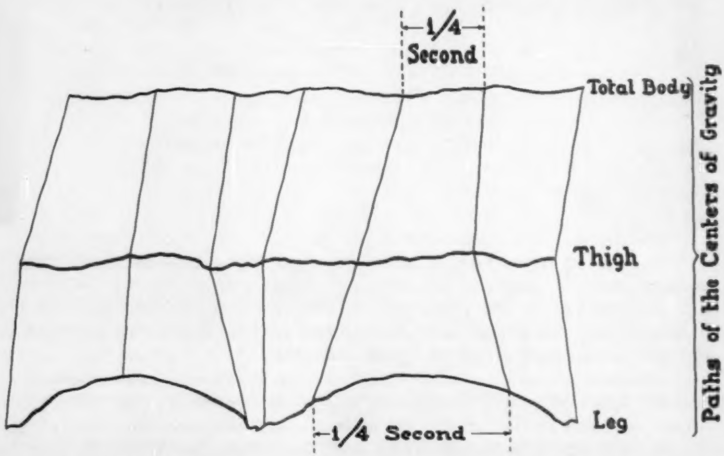


Fig. 4. Pictorial curve obtained by projecting successive frames of 16 mm. film and plotting the paths of the selected centers of gravity.

be emphasized that these curves are not calculated but are merely graphic representations of the sequential frames of the movie film.

(2) Time factor as revealed by footprints. It is obvious even to

Fig. 5. The pictorial curves were obtained by having one person plot the spots photographed on parts of the body while another turned the film frame by frame through the projector.

the casual observer that the toddler holds the entire sole of one foot on the surface longer as he lifts the opposing leg than does the adult. Calculations of the time interval between movements of the two legs should yield quantitative measures of progressive integration of locomotion. These calculations were obtained from the cinema footprints. It will be recalled from the descriptions of the apparatus for photographing footprints that the pyramidal projections contracted as soon as pressure was released and that evaporated milk filled the space. Such footprint records made it possible to count the number of frames showing any part of a footprint at any instant.

Counting the footprints was facilitated by the use of a movieola, to which was attached an automatic counter. The movieola, an instrument commonly used in editing, provides for direct viewing of the film through a magnifying lens. The film, fed through sprockets similar to those on a projector, runs between a light and the viewing lens. The speed of projection can be controlled by the observer. A foot pedal control for starting and stopping left the observer's hands free for recording. An automatic counter checked each frame as it passed before the viewing lens. An illustration of the movieola is presented in Fig. 6.

It will be recalled that the films were exposed at the rate of 32 frames per second. In each series of consecutive steps frames were counted as follows:

(a) Those which showed prints of both feet on the same frame.

(b) Those which showed a print of only left or right foot, the opposing leg being moved forward through the air at that moment.

The diagram, Fig. 7, of a series of prints demonstrates the standard followed in counting the frames.

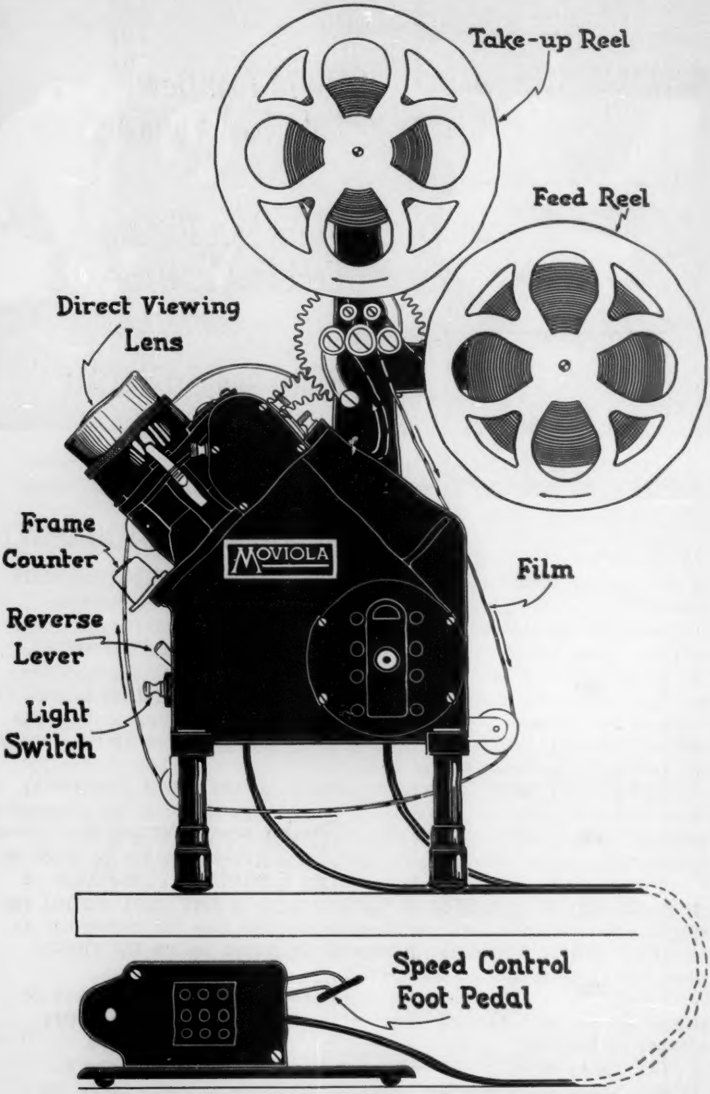


Fig. 6. Diagram of movieola employed in viewing and counting the frames exposed during each step.

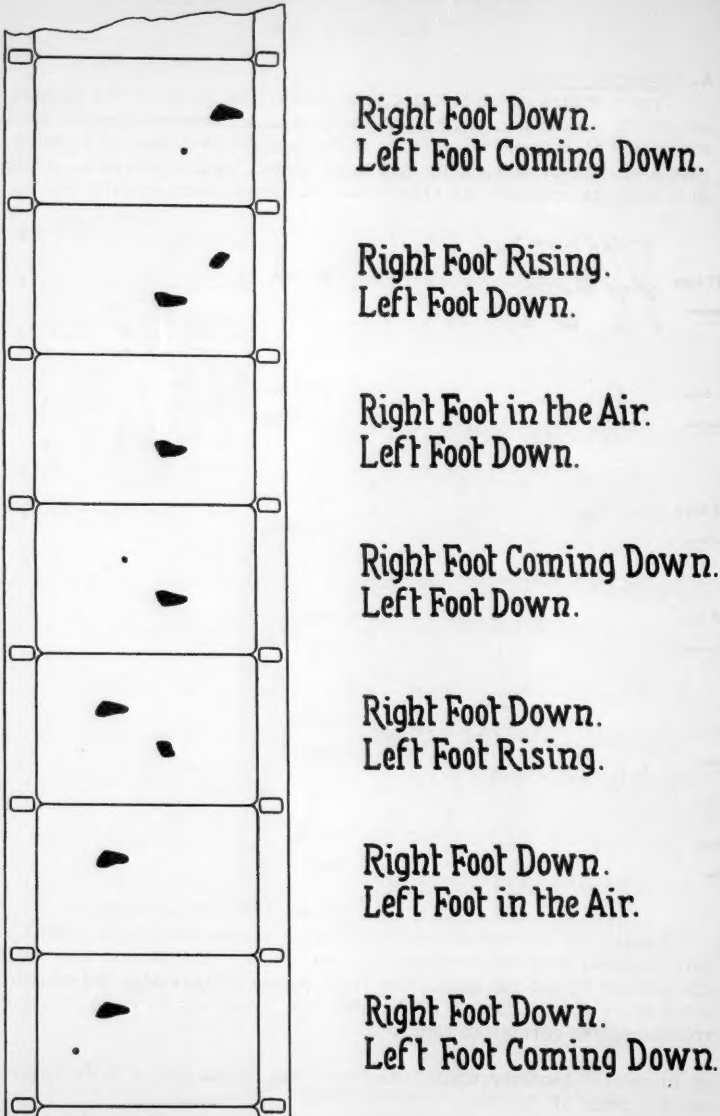
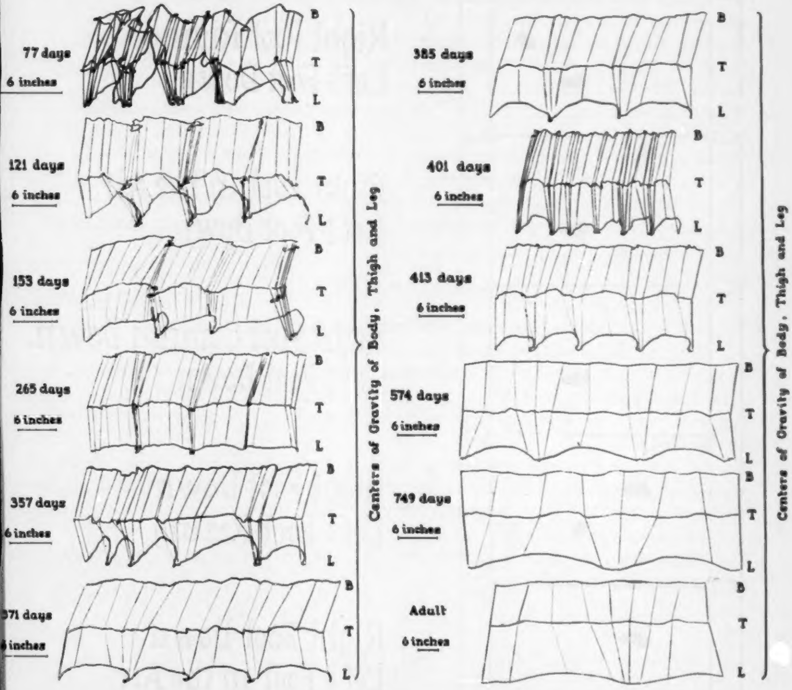


Fig. 7. A "step" was interpreted as the time consumed from a given position of the feet until that relative position was regained, as demonstrated by the series of successive film frames in the drawing.

ANALYSIS OF DATA

A. Pictorial Graphs

From a series of pictorial graphs showing the paths of the centers of gravity of the leg, thigh, and body, obtained from photographs of the same child at successive periods, it is possible to detect at a glance that a process of integration has taken place. Such a series of graphs on 1 child is presented in Figs. 8 and 9. Development is evidenced by



Figs. 8 and 9. The series of pictorial curves in Figures 8 and 9 were obtained from the pictures of 1 child taken at intervals between the ages of 77 and 749 days. The first curves representing independent walking are those taken at 401 days of age. The last curve in Fig. 9 represents the gait of an adult.

an increasing tendency toward smoothness and rhythm in the paths representing parts of the body.

Presented with a series of such pictorial graphs, the crucial problem is to select the most appropriate measurements on the graphs in order to convert the pictorial into a numerical presentation of development. The curves lend themselves to various determinations. One naturally thinks

of those measurements which would indicate the obvious elimination of waste motion and reflect progressive organization of the function. But the task of translating the pictorial graphs into numerical values is both tedious and costly. Concentration upon one, or at best a few, measurements seemed advisable. On inspection of the series of pictorial graphs it was apparent that the most gross and obvious developmental changes are reflected by the path of the leg.

It may be observed from the path of the center of gravity of the lower leg that two major changes take place with advancing time: first, the height of the center of gravity of the leg decreases with age, and, second, the path becomes smoother with advancing age. Obviously, in terms of energy output, the infant just learning to walk pays more dearly for the distance covered than does the adult. Not only is greater energy expended in lifting the leg higher, but considerable waste motion is apparent in the irregular path which the leg takes through space. The efficient step is one wherein the minimum energy necessary is expended in covering a given distance. Therefore an <u>efficiency</u> index of walking may be defined as the ratio between the horizontal distance covered and the length of the path of the center of gravity of the lower leg.

$$e.i. = \frac{L}{S} 100$$

where L = horizontal distance covered, and S = length of path. A series of such indices obtained at different periods during the child's life would serve as a measure of development in the efficiency of walking. When these successive indices are plotted against chronological age the rate at which the child is developing in efficiency of walking can be determined.

It was a difficult problem to measure accurately the length of the path, but it was achieved by using a small mimeographing stylus which could be rolled by hand over the curve. The stylus was calibrated in centimeters, and one prong was slightly bent to facilitate counting. The curve was rolled over carbon paper. The record obtained appeared as illustrated in Fig. 10.

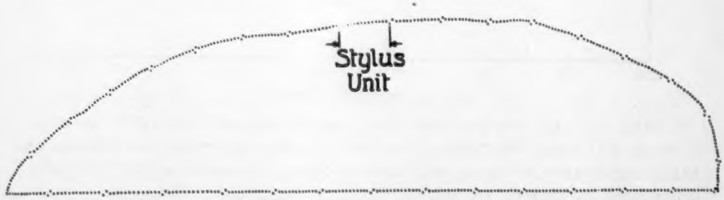


Fig. 10. Path of center of gravity of leg as shown on the carbon copy after the original was rolled with a small mimeographing stylus.

Fig. 11 shows a plot of the <u>efficiency index</u> versus age for one child.

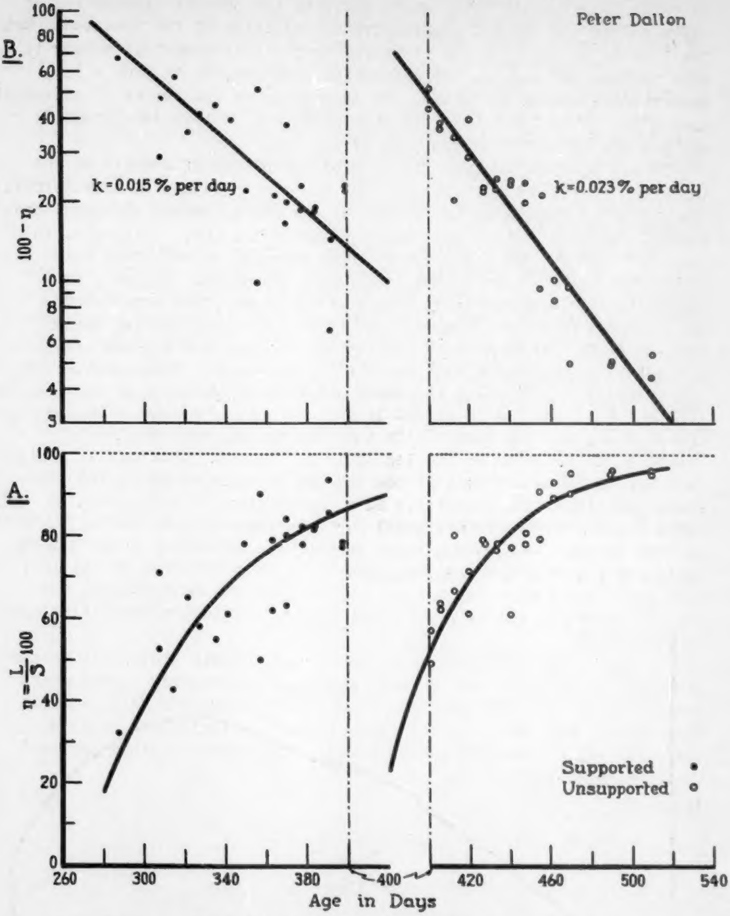


Fig. 11. A. Plot of efficiency index versus age for 1 child. B. Plot of 100 minus "efficiency index" on semi-log paper versus age for child shown in A. The slopes of the fitted lines give the "velocity constants" of growth in the "efficiency index".

Naturally, a hypothetically "perfect" step is not achieved by this method, since L is always less than S. But actually a value of about 98 per cent was achieved at 2 to 3 years of life. This index does seem to be a fairly good measure of the development of "efficiency" of locomotion. This index is capable of manipulation, in so far as the curve could conceivably be fitted by an exponential curve, and the rapidity

of approach to the asymptote, 100 per cent, be obtained. Subsequently different children could be compared as to their respective "velocities" of development of this aspect of locomotion. Such comparisons were not made because the stylus technique was too laborious to adopt in analyzing a large number of graphs.

The smooth curves shown passing through the points on the graph of Fig. 11 were obtained by fitting exponentials. For this child, Peter Dalton, the "velocity constants" for the supported and unsupported periods are respectively 1.5 per cent per day and 2.3 per cent per day as given by the slopes of the fitted lines when log (100 - e.i.) is plotted against age.

Since the stylus technique was too laborious to justify extensive measurements of the pictorial graphs the "projectile theory" was devised in order to facilitate the computation of numerical indices for additional children. The theory proposes that a muscular twitch sets the leg in motion so that it follows the path of a projectile through the air. It is obvious that in reality the leg can never wholly obey the rules of a projectile (in vacuo) because of friction in the joints, the fact that the leg is hinged to the body, the internal friction of the muscles, and the possibility that the muscles may accelerate or restrict the movement of the leg while in the air. However, it is conceivable that the movement of the leg may be represented by the time-space relations of a projectile in a hypothetically viscous medium (not air). Indeed the early pictorial curves of the path of the center of gravity of the leg have the appearance of the path of a projectile distorted by being in a viscous medium.

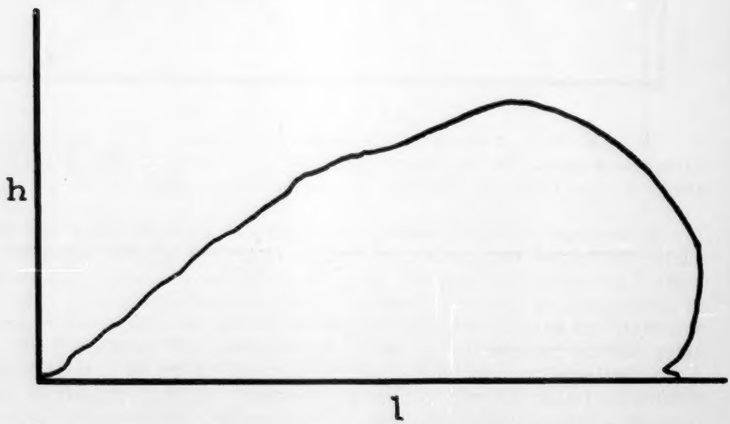


Fig. 12. Appearance of path of center of gravity of leg of a young infant inserted here to illustrate the similarity to the path of a projectile distorted by being in a viscous medium.

The later steps are much more nearly like a projectile in vacuo. Such

changes possibly indicate that the restrictions imposed in early life have been removed and the step has become a more efficient one. The fact that at a later stage of development the path of the leg does follow closely the path of a projectile (a parabola) may be seen by plotting the ratio of the vertical distances to the horizontal distances against the horizontal distances.

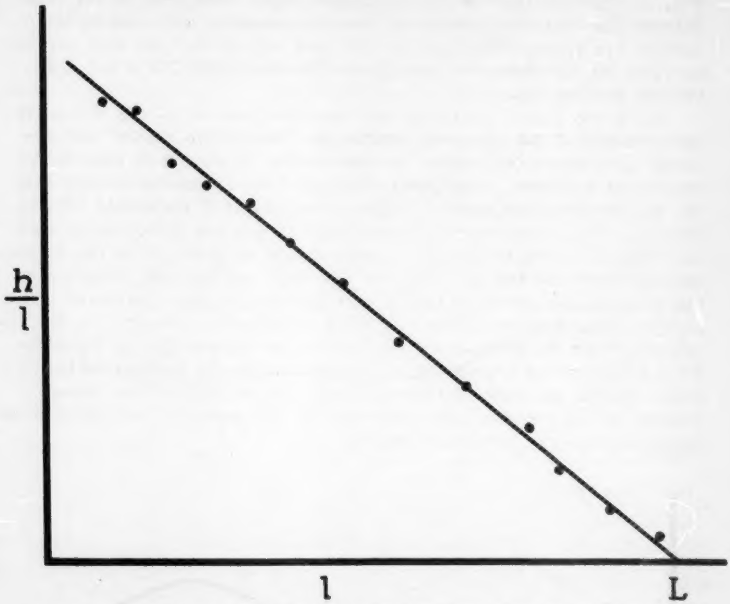


Fig. 13. Plot of ratio of the vertical distances to the horizontal distances against the horizontal distances for a typical step to illustrate the similarity to the path of a projectile (a parabola).

In the type of walking which precedes heel-toe progression, that is, during the period when the entire surface of the foot either comes in contact or leaves the ground at once, the entire step (path of the center of gravity of the leg) may appear to be approximately parabolic. The course of the path at this time may be determined by a sudden accelerating impulse imparted to the leg by the muscles. On the other hand, during heel-toe progression the acceleration may be due to a more gradual impulse of longer duration occurring throughout the time any part of the foot is in contact with the ground. Consequently, for subsequent measurements on the pictorial graphs the "beginning" and "ending" of the "step" were taken somewhat above the minimum horizontal at a point where presumably the toe has left the ground as shown in the diagram.

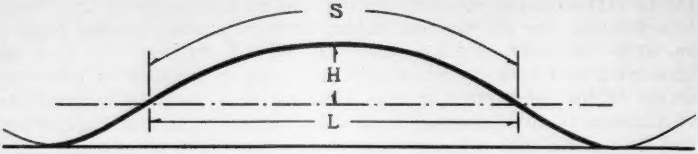


Fig. 14. Diagram to illustrate where the horizontal distance, L, and the vertical distance, H, were measured.

Three simple measurements may now be taken directly from the pictorial graphs, and the changes in these measurements noted with age: the vertical height, H; the horizontal distance, L; and the duration, T_2, in seconds. The curves in Fig. 15 show for 3 different children

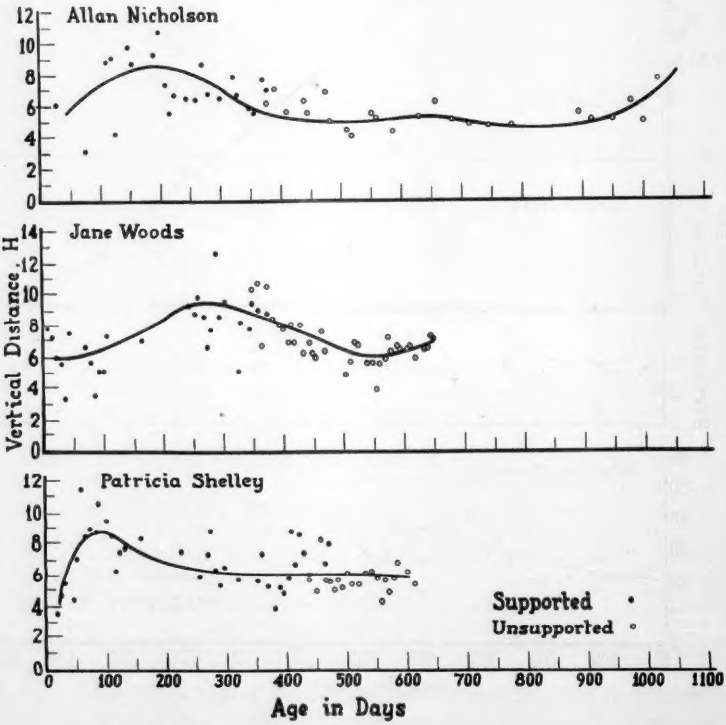


Fig. 15. Plot of vertical height, H, to which the center of gravity of the leg is lifted versus age, for 3 different children.

changes in the vertical height to which the center of gravity of the leg is lifted during stepping plotted against chronological age. There is a tendency for the vertical height curve to plateau between 4 and 8 cm. after the onset of independent walking. In children of 5 to 6 years this level is raised to from 6 to 9 cm. Such an increase in the vertical height of the leg lifting at this later point is possibly attributable to increase in foot length. Since mature stepping is from heel to toe the older child with a longer foot would either have to lift the leg higher, flex the ankle quicker as the foot leaves the surface or drag the toes on the floor.

The curves in Fig. 16 show the trend of development in the same 3 children when the horizontal distance traversed by the center of gravity of the leg is plotted against chronological age.

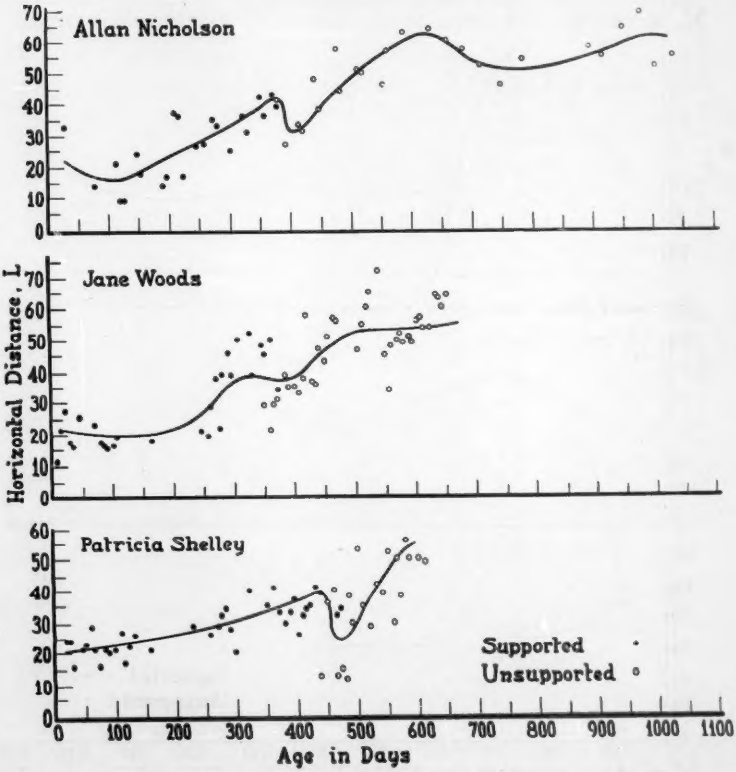


Fig. 16. Plot of horizontal distance, L, traversed by the center of gravity of the leg versus age for 3 children.

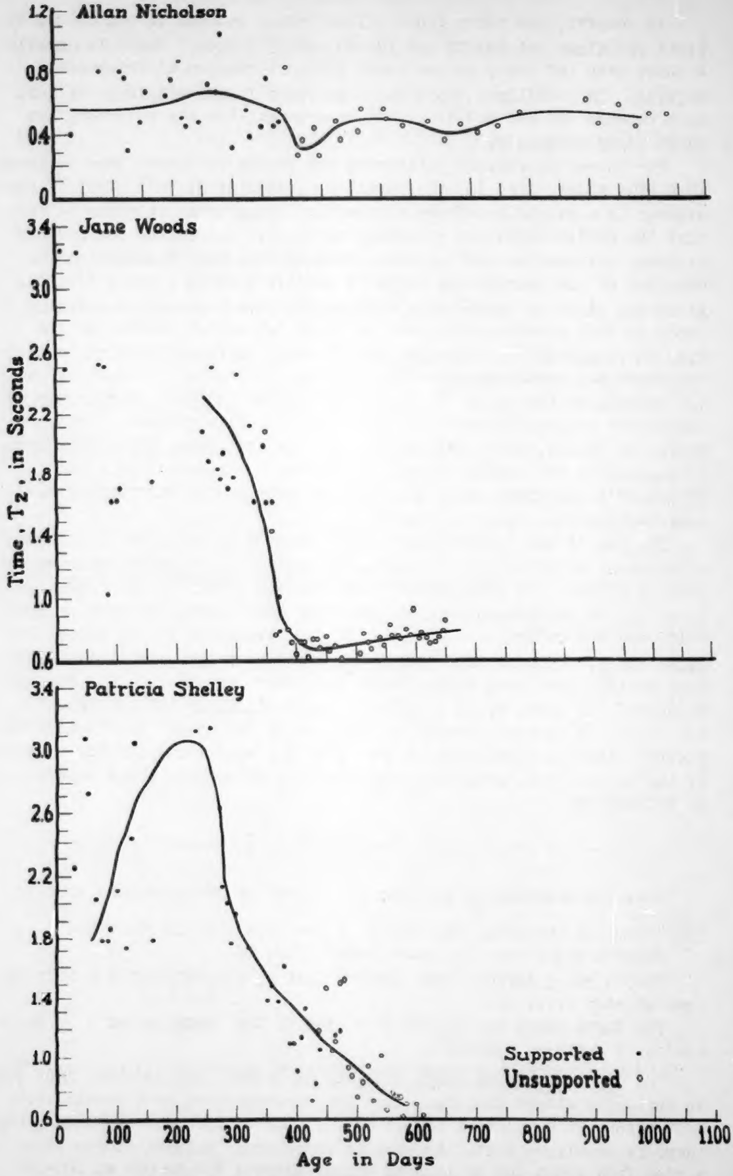


Fig. 17. Plot of the duration in seconds of each step, timed for the horizontal distance, L, versus age for 3 children.

In general, the curve rises - from values between 10 and 25 cm. at birth to values between 70 and 100 cm. at 2100 days. There is usually a sharp drop (of about 50 per cent) at the inception of independent walking. In 3 children there was a decrease in the magnitude of L at ages between 650 and 900 days, but in general, for all children, the curve rises gradually.

The curves in Fig. 17 illustrate the course of these three children when time alone, that is, the duration in seconds of each step, is considered as a single developmental factor. In general it might be said that the reflex steps are extremely variable. Appraising the records of other children as well as those presented in the illustration the duration of the pre-walking steps is usually between 3 and 6 seconds. After the onset of independent walking the time consumed in stepping tends to fall precipitously to a level of 0.5 to 0.7 seconds by the time an integrated gait becomes established. Although a slight rise in the curve may occur subsequently, it tends to plateau at about 0.7 to 1.0 seconds by the age of 5 years. This later increase in time may be attributed to some extent to an increase in length of step. These remarks, of course, are very general. An atypical case, Allen Nicholson, is shown with two typical cases. Note that the duration of Allen Nicholson's supported steps are much the same as his unsupported, and considerably less than the other two.

The use of the "projectile theory" enabled us to devise 2 indices of development of efficiency in locomotion using the 3 simple measurements just described. To some extent these indices eliminate the change in these simple measurements associated with the increase in size of the child and the concomitant increase in the dimensions of the step. The first index, which we have termed η_1, has been called the "form factor". This factor takes into account both the length of the step, L, and the height of the step, H, in such a way as to eliminate the changes in L and H with an increase merely in the size of the step. The "projectile theory" gives us a parabola of the form, $h = -al^2 + bl$, for the equation of the path of the center of gravity of the lower leg. This equation may be written as:

$$h = -\left(4\frac{H}{L^2}\right)l^2 + \left(4\frac{H}{L}\right)l$$

Now, the quantity $\frac{H}{L^2}$ measures the "form" of the parabola, that is, the "form" of the step, regardless of the mere size of the step.

Steps A and B have the same "form" (Fig. 18).

Step C has a larger "form factor" than A, and represents a more mature form of step (Fig. 19).

The curve shown in Fig. 20 is a plot of the "form factor", $\frac{H}{L^2}$ versus age for 3 children combined.

The curve starts at birth with values between 100 and 150, then there is (often) a slight drop for about 100 days followed by a steady rise, in most cases, to a value of 200 or to the time of independent walking when there is usually a fall. As soon as independent walking starts there is a rise from about 100 or less to values between 450 to 800 at 500-800 days of age, after which the curve may drop but usually plateaus. The

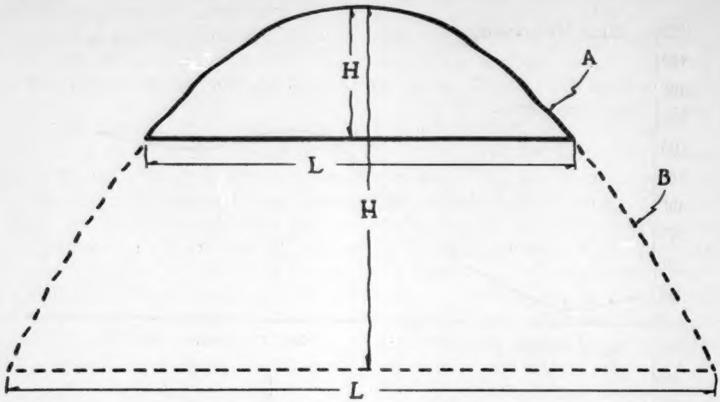


Fig. 18. Diagram of 2 steps A, for a small child, and B, for a large child, having respectively, the same "form factor".

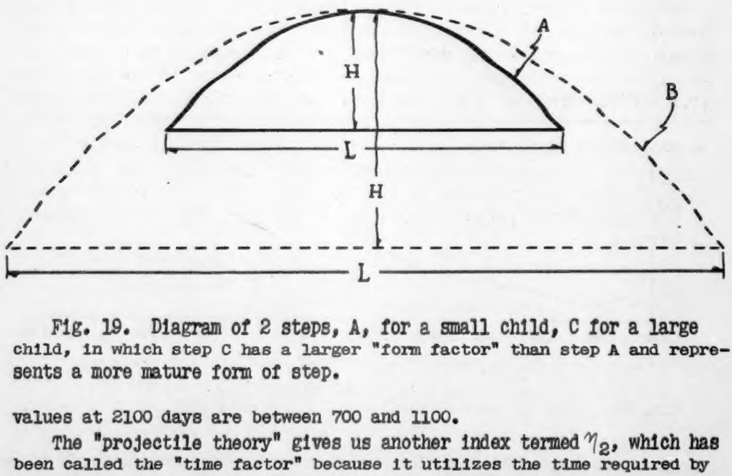


Fig. 19. Diagram of 2 steps, A, for a small child, C for a large child, in which step C has a larger "form factor" than step A and represents a more mature form of step.

values at 2100 days are between 700 and 1100.

The "projectile theory" gives us another index termed η_2, which has been called the "time factor" because it utilizes the time required by the center of gravity of the leg to reach the same horizontal as at the beginning of the step. This factor may conceivably give a truer picture of the energetic efficiency of taking a step than any of the other measures. In a crude sense, this factor, η_2, gives the ratio of the energy required by a projectile traveling the horizontal distance, L, to the average kinetic energy required by the leg in traversing the same distance and along its own (irregular) path, for if the average kinetic

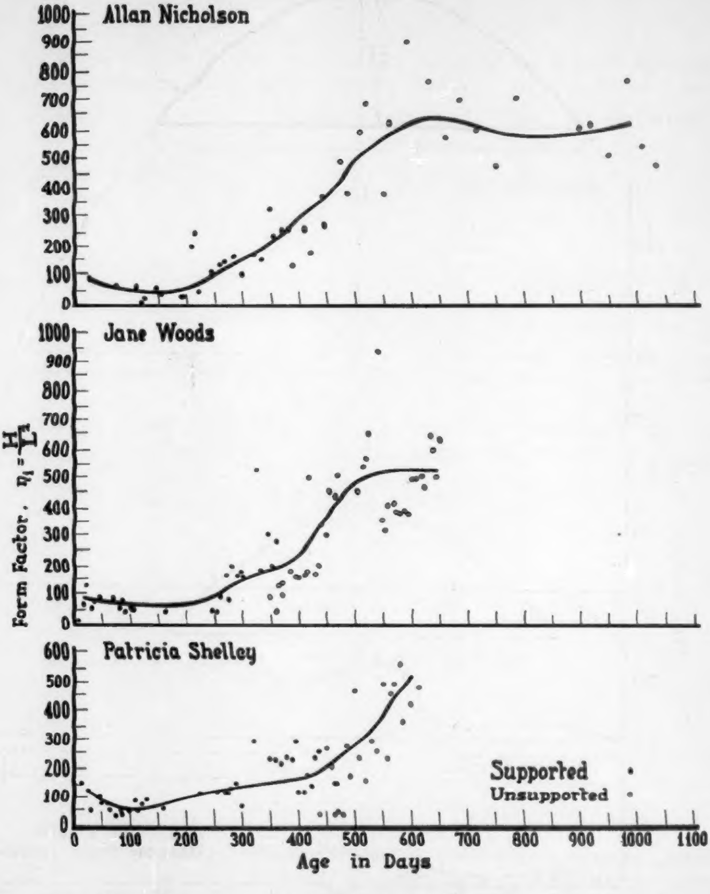


Fig. 20. Plot of the "form factor" $\frac{H}{L^2}$, versus age for 3 children.

energy of the leg is greater than the average kinetic energy of the projectile, there must be some waste energy expended in moving the leg, that is, in retarding or restricting its motion. The "time factor", then, is given by the ratio of the average kinetic energy of the leg to the average kinetic energy of a projectile traversing the same path,

$$\eta_2 = \frac{E_1}{E_p} = \frac{\frac{1}{2}m\bar{V}_1^{\,2}}{\frac{1}{2}m\bar{V}_p^{\,2}} = \frac{\bar{V}_1^{\,2}}{\bar{V}_p^{\,2}} = \frac{S^2/T_2^{\,2}}{S^2/T_1^{\,2}}$$

$$\eta_2 = \frac{T_1^2}{T_2^2}$$

The graph below is a plot of the "time factor" versus age for the same three children. The time for the projectile is given by $T_1 = \sqrt{\frac{8H}{g}}$ where g is the acceleration due to gravity.

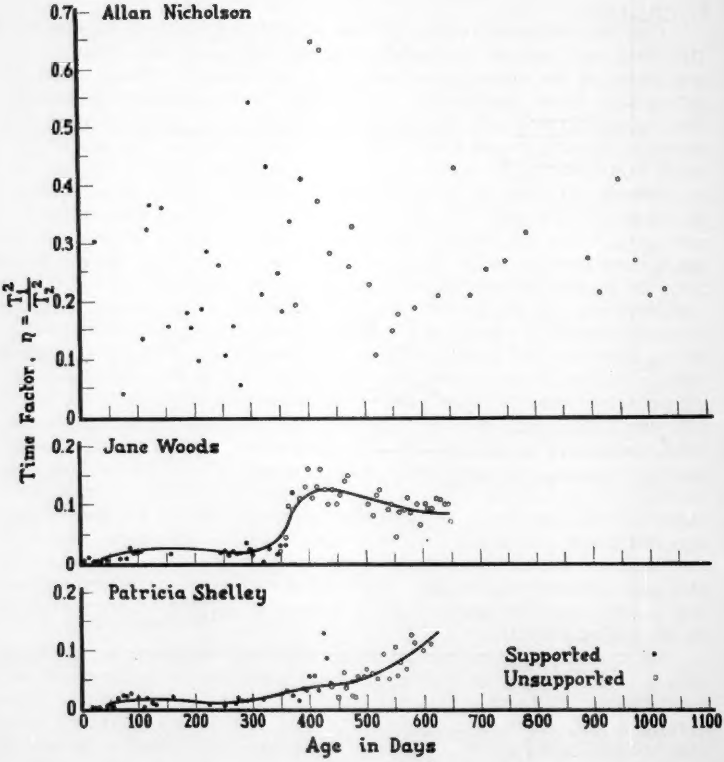


Fig. 21. Plot of the "time factor" $\frac{T_1^2}{T_2^2}$, versus age for 3 children.

At birth the "time factor" is 1 per cent or less. The curve shows a slight rise to about 2 per cent at 100 days of age, then shows little change until (in some cases) a slight rise to 5 to 10 per cent just before independent walking. The "time factor" varies between 2 and 10 per cent when independent walking starts, then rises to about 15 to 25 per cent at 400 to 600 days, after which there is usually a decline of about

10 per cent followed by, generally, a rise of about 5 per cent to what seems like a plateau. At 2100 days the "time factor" is between 10 and 20 per cent. Note that Allen Nicholson is atypical in his "time factor" due to the fact that the duration of his supported steps was much the same as his unsupported and considerably less than the other two children shown. All other children observed but not shown here followed a similar course to that of Jane Woods and Patricia Shelley.

B. Footprints

From the footprint records it was possible to obtain a measure of the time both feet were on the ground, and the time each foot alone was on the ground as the opposite one swung through the air. It was to be expected that these time factors would become more constant from step to step as the child's gait became better integrated. At the time of each recording several consecutive steps were photographed. The number of steps varied naturally according to the age of the child. However, on 8 different children the movie frames were counted which measured the time during which both feet were in contact with the surface during each step. Then the average time for the several steps recorded on any one day was determined as was also the average deviation. It can be seen from the individual records in Figs. 22 and 23 that both the average time both feet were on the ground and the average deviation dropped markedly after the onset of independent walking. Most of the children showed a period after the reflex stepping when no step could be elicited. These records not only show increasing consistency in the steps as the gait became established but also reflect temperamental differences in the individual children. Some children will not venture independent steps until the neural mechanisms are well connected. Such children do not show at the onset of independent walking a marked increase in time when the two feet are on the floor nor an increase in variability of steps comparable to the change in these factors manifested by the more aggressive child who will attempt to step with a less mature neural structure. The curves on the Putney twins illustrate these qualities as contrasted with the curve of Jane Woods. Four of the children (the Dalton twins, Jane Woods, and Patsy Shelley) were exposed to daily laboratory practice in the act of stepping.

The data obtained by measuring the time both feet were on the floor were not satisfactory in furnishing an accurate record of progressive development. It is true that the toddler tends to steady himself before lifting a leg, and this tendency reflects a lack of equilibratory control. Also when he lifts a foot he raises the entire sole almost at once. On the other hand the older child who steps from heel-to-toe may during any one step show prints of both feet on a comparable number of frames, but only a part of each sole is in contact with the surface. A more accurate measure would have to take into account the spatial as well as the time factor. We did not undertake the more precise measurements because of the magnitude of the work required and because the time factor alone demonstrated a general trend which showed consistency from child to child. Furthermore, spatial determinations of footprints would have to be reckoned in terms of anatomical growth of the foot.

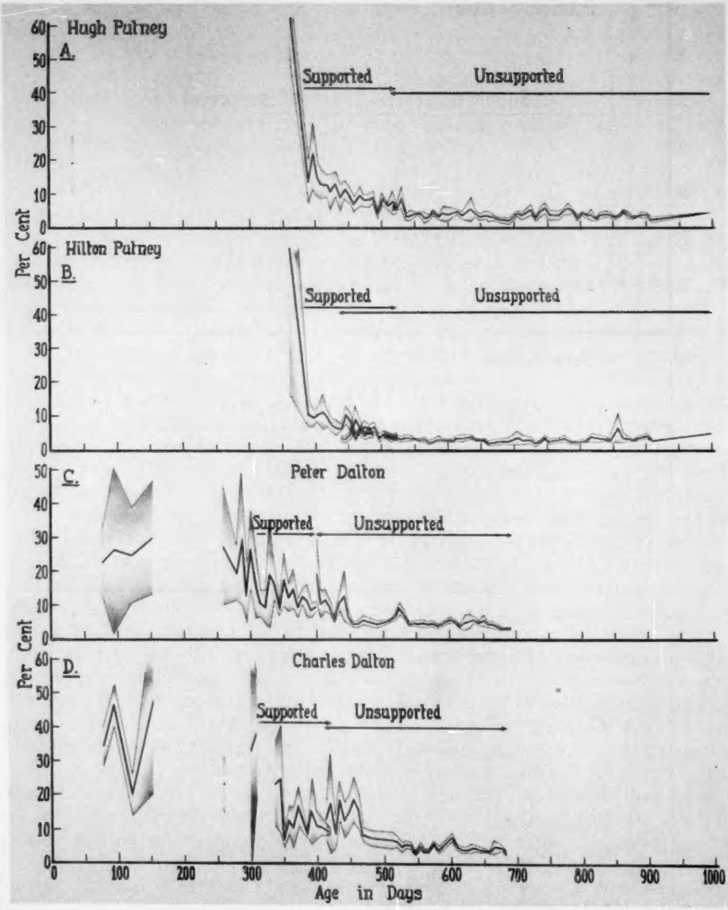


Fig. 22. Curves on 2 sets of identical twin boys show the average time during a step that both feet were on the floor. The average deviation is indicated by the shaded area.

The average time during which the child was actually bearing the weight on one foot as the other passed through the air was also calculated for one child, Jane Woods (curve C, Figure 23). Since these data do not reveal anything strikingly different from those based upon the time both feet were on the floor, these calculations were not

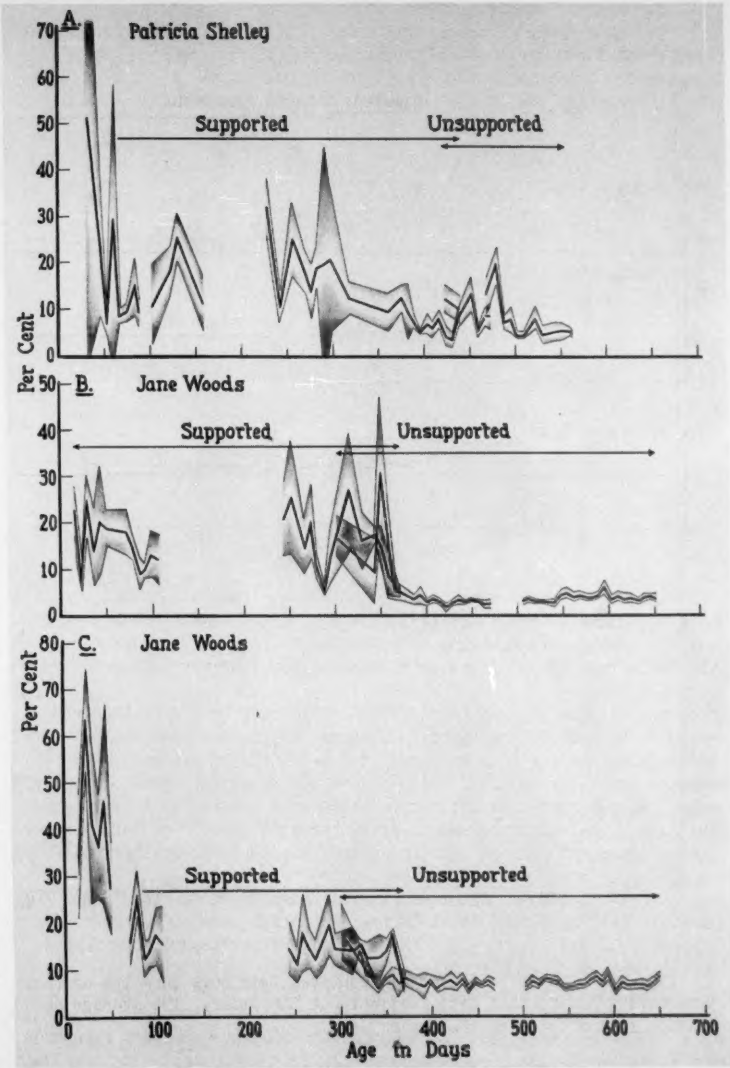


Fig. 23. Curves A and B show the average time during a step that both feet were on the ground as obtained in the measurements of 2 unrelated girls. Curve C shows for 1 child the average time 1 foot was on the floor as the opposite foot moved forward.

made for all the children.

The trend toward progressive integration in locomotion was further demonstrated by ascertaining the percentage of time consumed in a complete step during which both feet were on the floor. A curve illustrating calculations of this order is presented in Fig. 24 as obtained

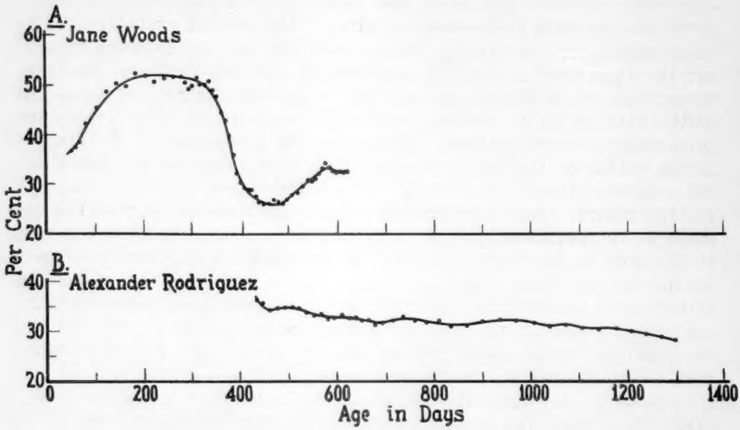


Fig. 24. Curve A shows the percentage of time during each step that both feet were on the floor as obtained from the measurements of one child. Additional measurements on an older child (Curve B) indicate that the percentage tends to become stabilized about 30 per cent.

from the records of Jane Woods. This child took her first independent steps shortly after the age of 300 days. At that age she had both feet on the floor during 50 per cent of the total stepping time. This percentage gradually declined and was just beginning to become stabilized around 30 per cent when the observations were terminated at the age of 600 days. That this percentage of 30 per cent is representative of an integrated child gait is evident by the calculations on older children, an illustration of which is presented in Curve B of Fig. 24 by the curve on A. Rodriquez. It is further substantiated by calculations of an adult gait which show that during a complete step 30 per cent of the time is consumed in swinging the foot forward and that during 70 per cent of the time the foot is on the floor.

After the gait has become established it is to be expected that during a series of consecutive steps the bilateral components of walking tend to become equal, that is, the amounts of time each foot spends on the floor and in the air are essentially the same. In faulty or unstable gaits these bilateral factors are not symmetrical. In order to reduce the measures to a common unit, a step has been calculated from the moment of a ground stroke by one foot until it strikes the ground again. Within this arbitrary unit, the percentage of time each foot is on the ground and in the air can be determined. Such percentages provide a means of

appraising the symmetry or asymmetry of gait. If the time during which each foot is on the ground and in the air is equal for the two feet, then the percentage of time during one step consumed by the action of each foot would be 50 per cent.

The curves (A and B in Fig. 25) show that this equalization of time devoted to the movement of each foot is being approached in the case of Jane Woods at about the age of 600 days, a little less than 300 days after the onset of independent walking. This gradual stabilization is illustrated more graphically in the curve "C" of Fig. 25 which brings out the difference in the time consumed in the action of the two legs. Toward the end of the second year this difference approaches zero. The curves also indicate that even after the inception of erect locomotion development is not uniformly bilateral. The percentage of difference in the action of the two legs oscillates, with first one leg and then the other requiring a longer time for action before relative equalization occurs. That the tendency toward equalization of the time consumed in the action of the two legs is a distinctly developmental trend is apparent in the curve of G. Gibaja upon whom records were made until the age of 1300 days. In general, it appears that in a well developed child's gait about 70 per cent of the time in stepping is consumed in the ground stroke of the foot and during approximately 30 per cent of the time the leg is moving through space. If the gait is symmetrical then the total action of each leg approximates 50 per cent and the difference in the time consumed by the action of each leg approaches zero. This stability of gait is usually attained toward the end of the second or the early part of the third year.

SUMMARY AND DISCUSSION

The present investigation was undertaken with the thought that the distinction between qualitative and quantitative data was due to a difference in our body of knowledge about phenomena and not to some inherent difference in the nature of things. Thus motivated our objective became one of devising means of measuring certain so-called qualitative aspects of behavior development. The degree of integration in any behavior function is a factor not easily reduced to numerical values. Yet it is an element common to all neuromuscular development. It was therefore taken as one of the qualitative factors for which we hoped to obtain numerical values. The reason for seeking numerical values for these factors is that symbolic data can be manipulated independently of the original facts, and therefore facilitate formulation of laws or principles of development.

Development of erect locomotion in the human infant, despite its complexity, was accepted as a function most easily subjected to measurements of this order. It was selected because techniques had already been devised for determination of the mechanics of walking. Modification of some of these techniques held promise as a means of measuring developmental changes in gait in spatio-temporal terms. The method finally adopted involved use of the motion picture film as an instrument of measurement. The child and an impression of the footprint during walking were photographed on the same film at varying intervals. Since the film

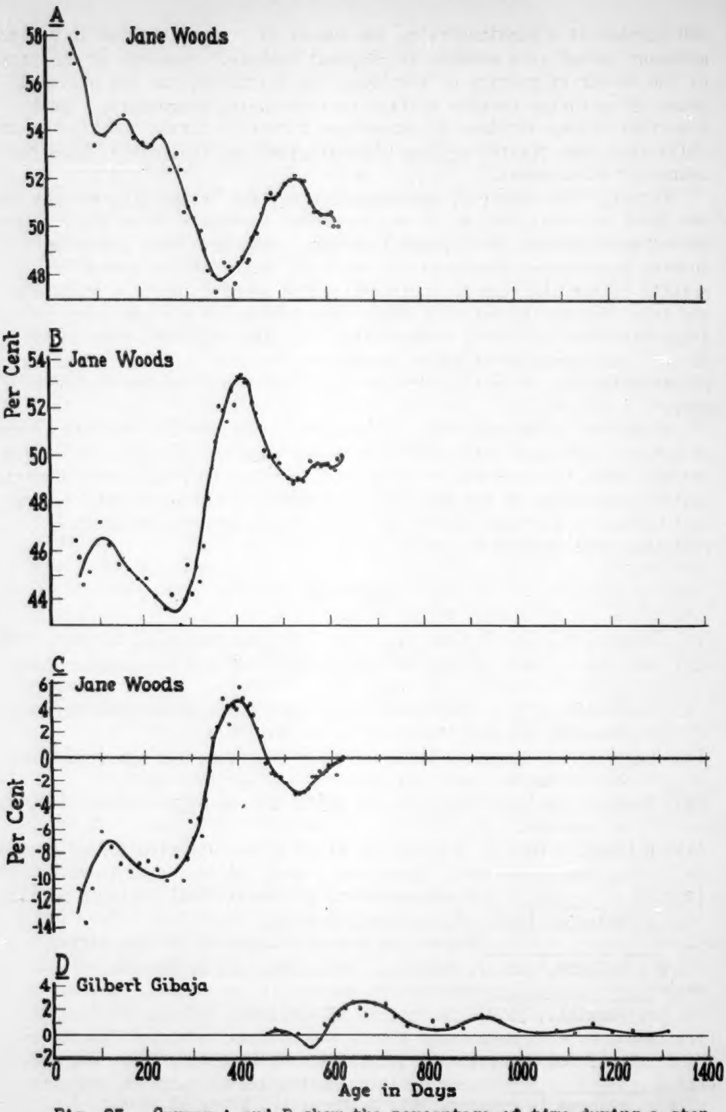


Fig. 25. Curves A and B show the percentage of time during a step that the left and right foot are in action. As the gait becomes integrated this value approximates 50 per cent. Curves C and D show the difference in the percentage of time each foot is in action. As the gait develops this difference approaches zero.

was exposed at a constant rate, the number of frames involved in a given movement served as a measure of temporal factors. Tracings of the paths of the center of gravity of the body, the thigh, and the leg provided means of measuring certain spatial factors during progression. Such numerical values obtained at successive intervals during the life of the child were then plotted against chronological age in order to show the course of development.

Actually the number of measurements provided by the film records was too great to cope with, so it was necessary to select those which represented most obvious developmental change. Data have been presented showing progressive change in the vertical height of the center of gravity of the leg, the horizontal distance covered during a step, and the time consumed in making a step. Development of a consistency in steps was shown in curves representing the time both feet were on the floor. The course of bilateral integration became apparent in curves representing the percentage of time each foot was in action during a step.

While the development of or increasing integration of certain aspects of walking have been delineated, additional measurements would have to be obtained from the records before the complete pattern of erect locomotion could be expressed in symbolic form. However, these measurements serve to demonstrate the possibility of converting complex neuromuscular functions into mensurable units.

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